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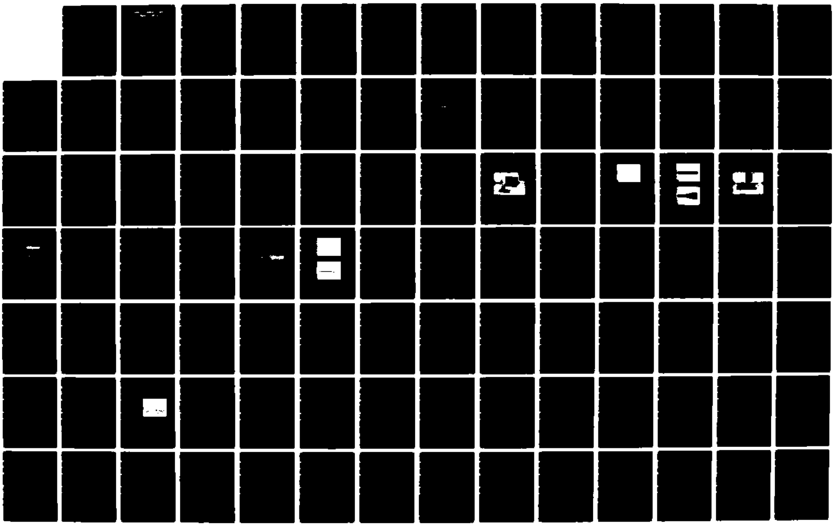

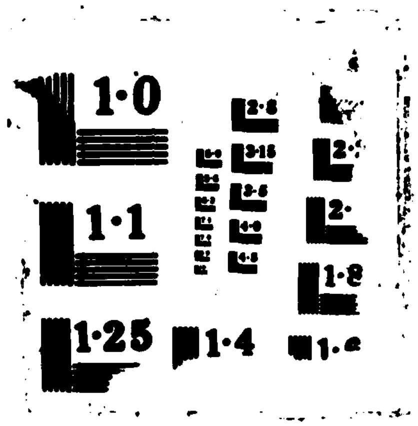
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NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

SCATTERING IMPULSE RESPONSE
SYNTHESIS USING
RANDOM NOISE ILLUMINATION:
INITIAL CONCEPT EVALUATION

by

Dong Il Lee

March 1988

Thesis Advisor: Michael A. Morgan

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This thesis investigates the synthesis of smoothed impulse responses using sampled data of the input and output of random noise driven electromagnetic systems. Special interactive software was developed for NPS's time domain electromagnetic scattering laboratory. The system performs signal acquisition, synthesizes time and frequency domain scattering responses using broad band random noise and provides results as easily evaluated graphic displays. Attempted validations of the system are made by comparing synthesized impulse responses for microwave filters and transient scatterers to alternate experimental and computational data. Keywords:

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Scattering Impulse Response Synthesis Using Random Noise Illumination: Initial Concept Evaluation

by

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B.S., Korean Military Academy, 1977

Submitted in partial fulfillment of the
requirements for the degree of

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ABSTRACT

This thesis investigates the synthesis of smoothed impulse responses using sampled data of the input and output of random noise driven electromagnetic systems. Special interactive software was developed for NPS's time domain electromagnetic scattering laboratory. The system performs signal acquisition, synthesizes time and frequency domain scattering responses using broad band random noise and provides results as easily evaluated graphic displays. Attempted validations of the system are made by comparing synthesized impulse responses for microwave filters and transient scatterers to alternate experimental and computational data.

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I. INTRODUCTION

A. OVERVIEW

The objective of this research is to demonstrate the viability of performing high-resolution impulse response scattering measurements using a broad-band noise source. The development of laboratory facilities for high-resolution impulse response scattering measurements has generally proceeded using two major techniques. The first of these employs a stepped-frequency coherent oscillator and a vector (magnitude and phase) receiver. Impulse response target characteristics are obtained via inverse Fourier transformation of the frequency domain data. The second method obtains impulse response measurements directly in the time-domain by use of a repetitive fast-pulse target illumination with a sampling-scope acting as the receiver. The time-domain approach for scattering measurements offers a viable alternative to the more prevalent continuous wave approach. Transient scattering measurements provide waveforms that can be more directly interpreted as to cause and effect and allow exact range-gating of target responses for elimination of unwanted clutter [Ref. 1, 2].

The development of digital sampling oscilloscopes and broad band noise generators made possible a third method for high-resolution impulse response scattering measurements. This technique is based on the estimation of the crosscorrelation function between input and output using a broad-band noise source as the transmitter. This methodology has been employed in measuring the mechanical impulse response of large structures, such as bridges and buildings [Ref. 3].

The practical advantages of this third technique are two-fold. The first is the wide bandwidth and high power available from noise sources which are available at much lower cost than comparable stepped-frequency sources. A conclusive demonstration of the viability of noise source impulse response measurements may lead to further refinements and ultimately to commercial marketing of this technology. The second advantage is related to the use of noise-source illumination for tactical and strategic radar applications. An obvious benefit would be the masking of the radar interrogation signal; this would appear at the target as either jamming or interference. Confusion would result as to proper countermeasures to be employed by the target. Furthermore, since this method uses random noise, which is orthogonal to other signals and other noise (producing zero crosscorrelation with these), a high SNR requirement could be achieved.

This thesis is a continuation in a series of efforts in transient electromagnetic scattering that began in 1979 at the Naval Postgraduate School (NPS). The development of digital sampling techniques allowed the development of transient scattering ranges in the late 1960's [Ref. 4]. A transient scattering range having sufficient bandwidth and signal to noise ratio (SNR) to support radar target identification was initially constructed at NPS in 1980 using a ground plane configuration [Ref. 5,6]. A very wideband (short pulse) free-field scattering range was then constructed in 1983 for implementation of target identification based upon natural resonances, as introduced by Mittra and Van Blaricum [Ref. 7]. This free field transient range was validated by Mariategui, and McDaniel [Ref. 8,9].

B. NOISE SOURCE IMPULSE RESPONSE MEASUREMENT CONCEPT

In the noise source impulse response measurement technique, a broad band noise signal is used as the input. The system impulse response is derived from measuring the crosscorrelation function between the input and output.

The configuration shown in Figure 1a has been used to implement the noise source impulse response measurement technique in the NPS scattering laboratory. It was thought at first that the Tektronix 7804 Digital Processing Oscilloscopes (DPO) would allow simultaneous measurements of both channels. After much effort, this was found to be untrue, as will be shown. A new method was developed, using the measurement of the difference of the input and output time sequence. A digital estimator of the crosscorrelation function is formed in the data processor for the measurement and the expectation of the crosscorrelation function, $R_{xy}(n)$, is obtained by further averaging of this estimator using N-block averages of the stored data.

The complete scattering measurement using a noise-source requires three steps. Looking at the scattering range system representation in Figure 1b, the target transfer function $H_t(f)$ will be evaluated by measuring $X(n)$ and $Y(n)$, the input and output of the respective transmitting and receiving antennas. The second step necessitates factoring out the effects of the antennas, in addition to eliminating the signal pollution of the spurious cross-coupling and clutter in the chamber. The following three measurements are made with equivalent system diagrams shown in Figure 2:

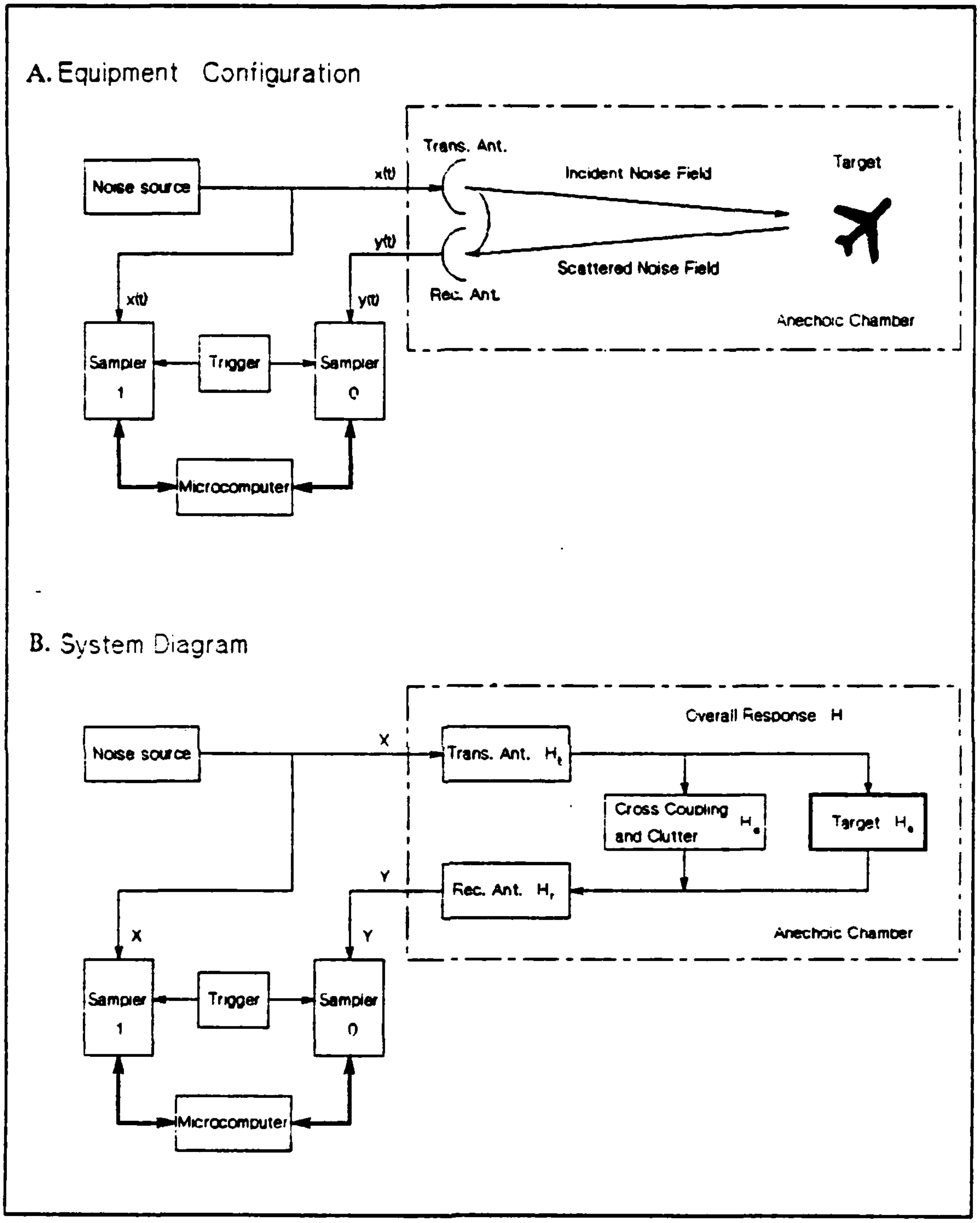
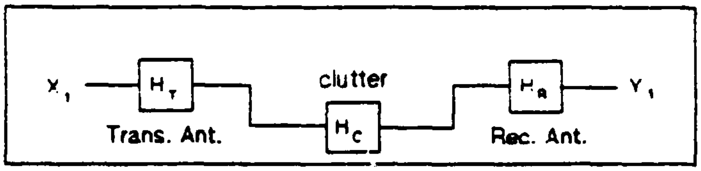


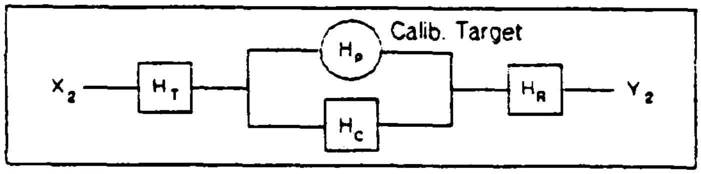
Figure 1. The Measurement of Noise Source Impulse Response

■ Step 1. : Background measurement (no target)



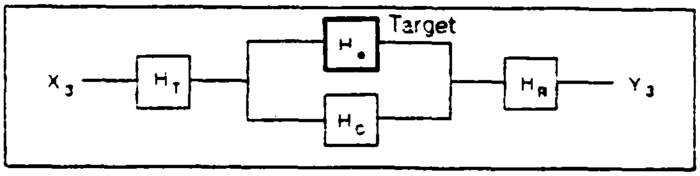
$$H_1(f) = H_t(f)\ H_c(f)\ H_r(f)$$

■ Step 2. : Calibration target (sphere) measurement



$$H_2(f) = H_1(f) + H_t(f)\ H_p(f)\ H_r(f)$$

■ Step 3. : Test target measurement



$$H_3(f) = H_1(f) + H_t(f)\ H_s(f)\ H_r(f)$$

■ Step 4. : Subtraction of the background effect

$$H_4(f) = H_2(f) - H_1(f)$$
$$H_5(f) = H_3(f) - H_1(f)$$

■ Step 5. : Extraction of the target response (Deconvolution)

$$\frac{H_5(f)}{H_4(f)} = \frac{H_t(f)\ H_s(f)\ H_r(f)}{H_t(f)\ H_p(f)\ H_r(f)} = \frac{H_s(f)}{H_p(f)}$$

For optimal compensation, use Riad's method

$$\frac{H_5(f)}{H_4(f)} \approx \frac{H_5(f)\ H_4(f)}{|H_4(f)|^2 + (\Sigma\ H_4^2(f))/N}$$

Therefore,

$$H_s(f) = \frac{H_5(f)\ H_4(f)}{|H_4(f)|^2 + (\Sigma\ H_4^2(f))/N} H_{pc}(f)$$

$H_{pc}(f)$: computed frequence response of the calibration target. (sphere)

Figure 2. The Procedure of Noise Source Impulse Response Scattering Measurement

1. No target present, measure $h_1(t)$
2. Calibration target (sphere) present, measure $h_2(t)$
3. Test target present, measure $h_3(t)$

Then, $h_1(t)$ will be subtracted from $h_2(t)$ and $h_3(t)$ to eliminate the clutter effect.

$$h_4(t) = h_2(t) - h_1(t) \tag{1.1}$$

$$h_5(t) = h_3(t) - h_1(t) \tag{1.2}$$

Finally, the desired impulse response is extracted from $h_4(t)$ and $h_5(t)$ using an optimal deconvolution technique known as Riad's method [Ref. 10] which will be described in detail in the following chapter.

An important difficulty encountered in this thesis research was that no sampling device with a high enough rate for the source signal, having a bandwidth of approximately 13 GHz, is available thus far. Consequently, the estimation of the crosscorrelation function could not be computed using a pair of properly sampled sets of the time function of each input and output signal. Two alternate methods were developed which, for the case of ergodic random noise, permits arbitrarily slow sampling to be used. These two Nyquist independent techniques will be described in Chapter II.

C. OVERVIEW OF THESIS

The objectives of this thesis were to:

1. Develop a working software program which will acquire transient response data from the target and compute the estimation of the crosscorrelation function followed by a computation of the system impulse response using a deconvolution technique.
2. Demonstrate impulse scattering response measurements using a broad band random noise source, and verify the performance in comparision with another technique: time-domain measurement using modified step function input.

Chapter II will expand the theory of noise source impulse response measurement. This will examine the basic theory of analog crosscorrelation techniques for acquiring system impulse responses and consider an appropriate derivation for the discrete version of the technique for the sampled signal. In addition, it will quantify the estimation of the crosscorrelation function.

Chapter III describes the experimental system in detail. This will include the description of the original Digital Processing Oscilloscope (DPO) and modifications that

were made. A description of the noise source hardware and its modified hardware will also be given in this chapter. In addition, the problems encountered in this research will be discussed and some guidelines for the laboratory work will be summarized.

Chapter IV contains the calibration and validation measurements for simulated targets. This will include the initial quality tests of simultaneous channel sampling, noise source, and crosscorrelation function that were made by sampled data using the noise source. The derivation of the crosscorrelation of the measurement itself (autocorrelation) and frequency response will be considered using FFT techniques. The initial test involving a microwave bandpass amplifier using a noise source and a step generator with amplifier will also be discussed.

Chapter V will describe the electromagnetic scattering measurement. The experimental setup, scattering range and characteristics of the antenna used will be explained. Finally, the impulse response measurement of a metal sphere target will be attempted using the noise source. The resultant failure of this measurement will be considered.

Chapter VI provides some conclusions about this experimental approach involving noise source impulse response measurements. Additionally, recommendations are made regarding improvements in the current system and possibilities for further research.

II. THEORY OF NOISE SOURCE IMPULSE RESPONSE MEASUREMENT

A. THEORY OF ANALOG SIGNAL CROSSCORRELATION

Looking at the system diagram in Figure 1b, the responses of transmitter antenna $h_t(t)$ and receiver antenna $h_r(t)$ are cascaded with the parallel responses of the target $h_s(t)$ and the clutter $h_c(t)$, forming an overall response, $h(t)$,

$$h(t) = h_t(t) * [\, h_s(t) + h_c(t) \,] * h_r(t) \tag{2.1}$$

The total measurement system can be represented as a simple linear system whose response, $Y(t)$, due to an input, $X(t)$, is given by the convolution

$$\begin{aligned} Y(t) &= h(t) * X(t) \\ &= \int_0^{\infty} h(\sigma) X(t-\sigma)\, d\sigma \end{aligned} \tag{2.2}$$

It can be shown that the crosscorrelation of the input and output of a linear system estimates the system impulse response when the input has a bandwidth that is large compared to the bandwidth of the system. This results from superposition as applied to stochastic expectation,

$$\begin{aligned} R_{xy}(t) &= E\,[X(\tau)\,Y(\tau+t)] \\ &= E\,[h(t) * X(\tau)X(\tau+t)] \\ &= h(t) * E\,[X(\tau)X(\tau+t)] \end{aligned}$$

$$R_{xy}(t) = h(t) * R_x(t) \tag{2.3}$$

For ergodic processes, the mean values and moments can be determined by time averages as well as by ensemble averages.

$$\begin{aligned} R_{xy}(t) &= \langle X(\tau)\,Y(\tau+t) \rangle \\ &= \int_{-\infty}^{\infty} X(\tau)\,Y(\tau+t)\, d\tau \end{aligned} \tag{2.4}$$

Replacing the output signal $Y(t)$ by the convolution defined in Equation (2.2) results in

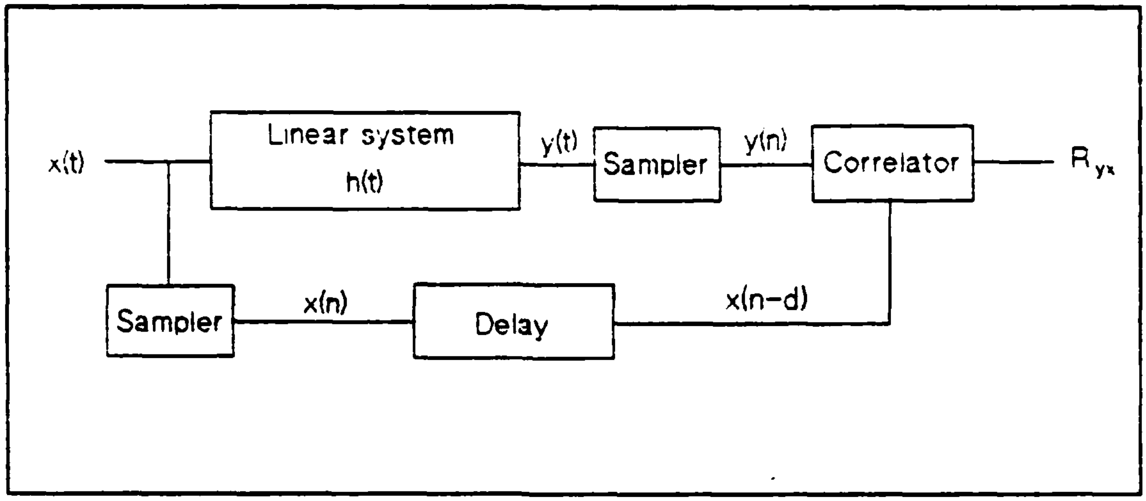


Figure 3. Crosscorrelation Measurement System Model

$$
\begin{aligned}
R_{xy}(t) &= \int_{-\infty}^{\infty} X(\tau) \int_{0}^{\infty} h(\sigma) X(\tau + t - \sigma)\, d\sigma d\tau \\
&= \int_{0}^{\infty} h(\sigma) \int_{-\infty}^{\infty} X(\tau) X(\tau + (t - \sigma))\, d\tau d\sigma \\
&= \int_{0}^{\infty} h(\sigma) R_x(t - \sigma)\, d\sigma \\
&= h(t) * R_x(t)
\end{aligned}
\tag{2.5}
$$

This leads to an important property of the Fourier transform relation, which is

$$S_{xy}(f) = H(f)\, S_x(f) \tag{2.6}$$

known as the crosscorrelation theorem [Ref. 11].

B. CROSSCORRELATION MEASUREMENT

1. Method 1. : Simultaneous Dual Channel Measurement with Sampling Rate Greater than Nyquist Frequency.

Three methods of performing the measurement could be used to estimate the crosscorrelation of the linear system. One possible, probably the most general, way is to directly sample the input and output sequence simultaneously and store the data in the computer memory. This involves a delay of the input sequence, and a computation of the average of the product of the two sequence vectors.

$$\tilde{R}_{xy}(n) = \frac{1}{K} \sum_{k=n}^{K-1-n} X_k Y_{k+n}$$

$$\tilde{R}_{xy}(n) = \frac{1}{K} \sum_{k=n}^{K-1-n} X(k)\ Y(k+n) \tag{2.7}$$

This scheme is illustated in Figure 4 and compared to other methods. Two conditions must be satisfied to use this method,

1. Sampling must be done with a sampling rate greater than the Nyquist frequency.
2. Sampling of two channels must be done simultaneously.

2. Method 2. : Simultaneous Dual Channel Measurement with Arbitrary Sampling Rate. (Less than Nyquist Frequency)

Method 1 could not be used because the required bandwidth of the DPO sampler is insufficient. An alternative method requires manually shifting the input (or output) signal, being incremented by the sampling interval. Samples of the input and output signal are taken with a suitable sampling rate, since each sampled time sequence is treated as the sample set of the ensemble space rather than a time sequence.

$$\hat{R}_{xy}(n) = \frac{1}{K} \sum_{k=0}^{K-1} X_{t,k}\ Y_{t+nT,k}$$

$$\hat{R}_{xy}(n) = \frac{1}{K} \sum_{k=0}^{K-1} X(kL)\ Y(kL+n) \tag{2.8}$$

where,

$$n \equiv nT \qquad \text{with} \qquad \frac{1}{T} \geq 2f_{\max} \tag{2.9}$$

$$T_s \equiv LT \qquad , \qquad L \gg 1 \tag{2.10}$$

Here, T denotes the time period of delay and T_s is the sampling period. Using this technique, the estimation of the crosscorrelation of the delayed time point can be computed by each measurement of input and output signal with an appropriate amount of delay. This method is illustrated in Figure 4. The remaining condition which must be satisfied for the crosscorrelation measurement is simultaneous sampling.

For the case of random noise, it looks like the direct measurement method under the high rate sampling environment. The second method was initially chosen for this research.

3. Method 3. : Pre-subtracted Single Channel Measurement with Arbitrary Sampling Rate. (Less than Nyquist Frequency)

During the laboratory work, it was shown that an unknown critical noise is added to the left sampling channel of the DPO which makes the second method impossible to use. This may be caused by mispositioning of the actual data in the buffer. This phenomena and the equivalent model are illustrated in Figures 5 and 6. An alternative method which avoids this problem is to subtract Y from X using the built in "Add" and "Invert" functions in the DPO. This results in only one sequence of pre-subtracted data and is followed by computing the estimation of the mean-square value of this data sequence.

Referring to Figure 6, assume that the impulse responses of the sampler channels of the DPO are unit impulse responses. (The effect of the sampler responses of the DPO will be discussed in the later section of this chapter.)

$$p(t) = q(t) = \delta(t) \tag{2.11}$$

Then the measured sequences $X_p(n)$ and $Y_q(n)$ can be denoted as

$$X_p(n) \equiv X(n) + D_x(n) + N_x(n) \tag{2.12a}$$

$$Y_q(n) \equiv Y(n) + D_y(n) + N_y(n) \tag{2.12b}$$

where,

$D_x(n)$: DC bias due to the DPO vertical adjustment.

$N_x(n)$: other noise. (thermal noise, jitter, quantization noise etc.)

with similar representations for $D_y(n)$ and $N_y(n)$ usig the Y-channel.

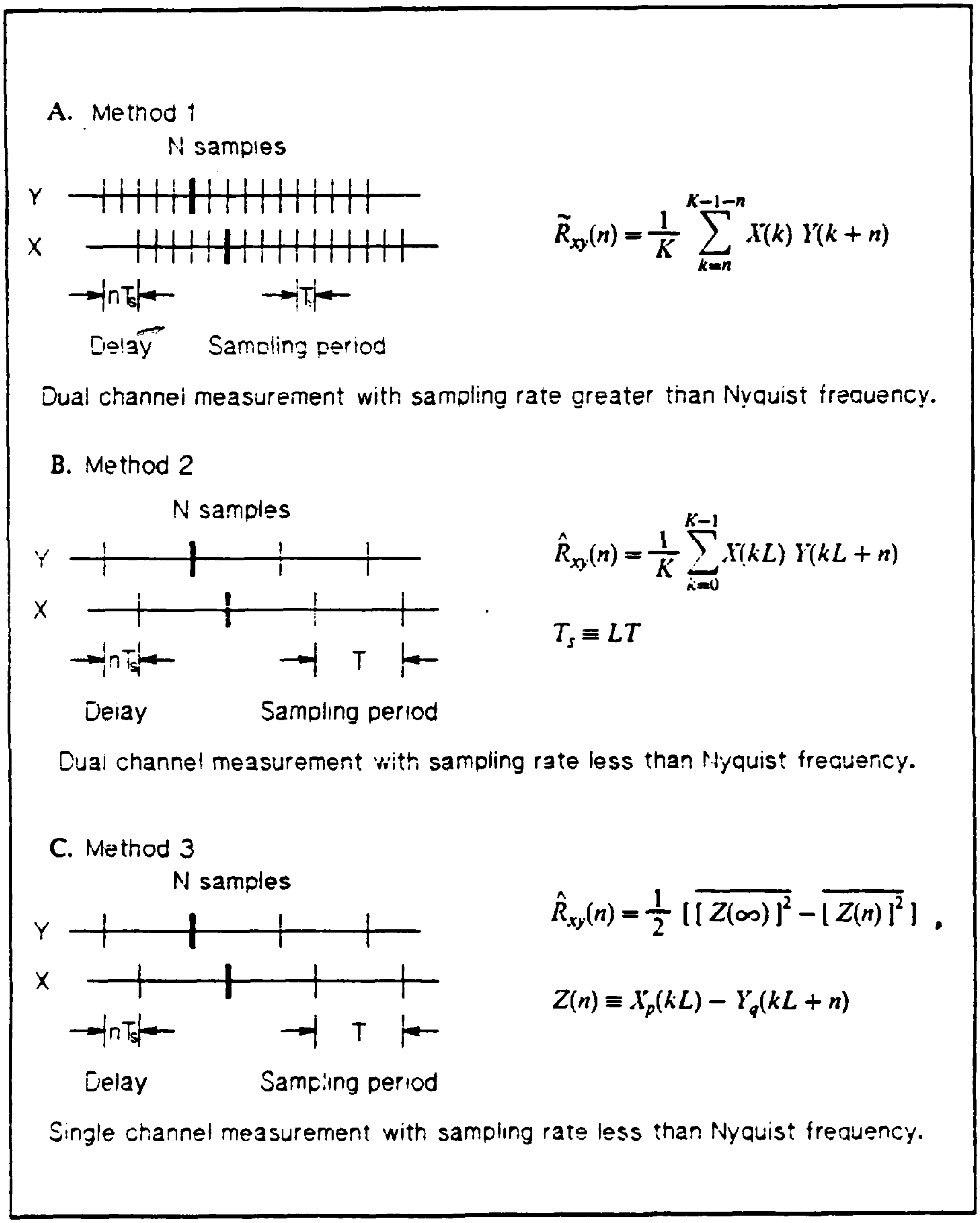


Figure 4. Comparison of The Three Estimation Techniques for The Crosscorrelation

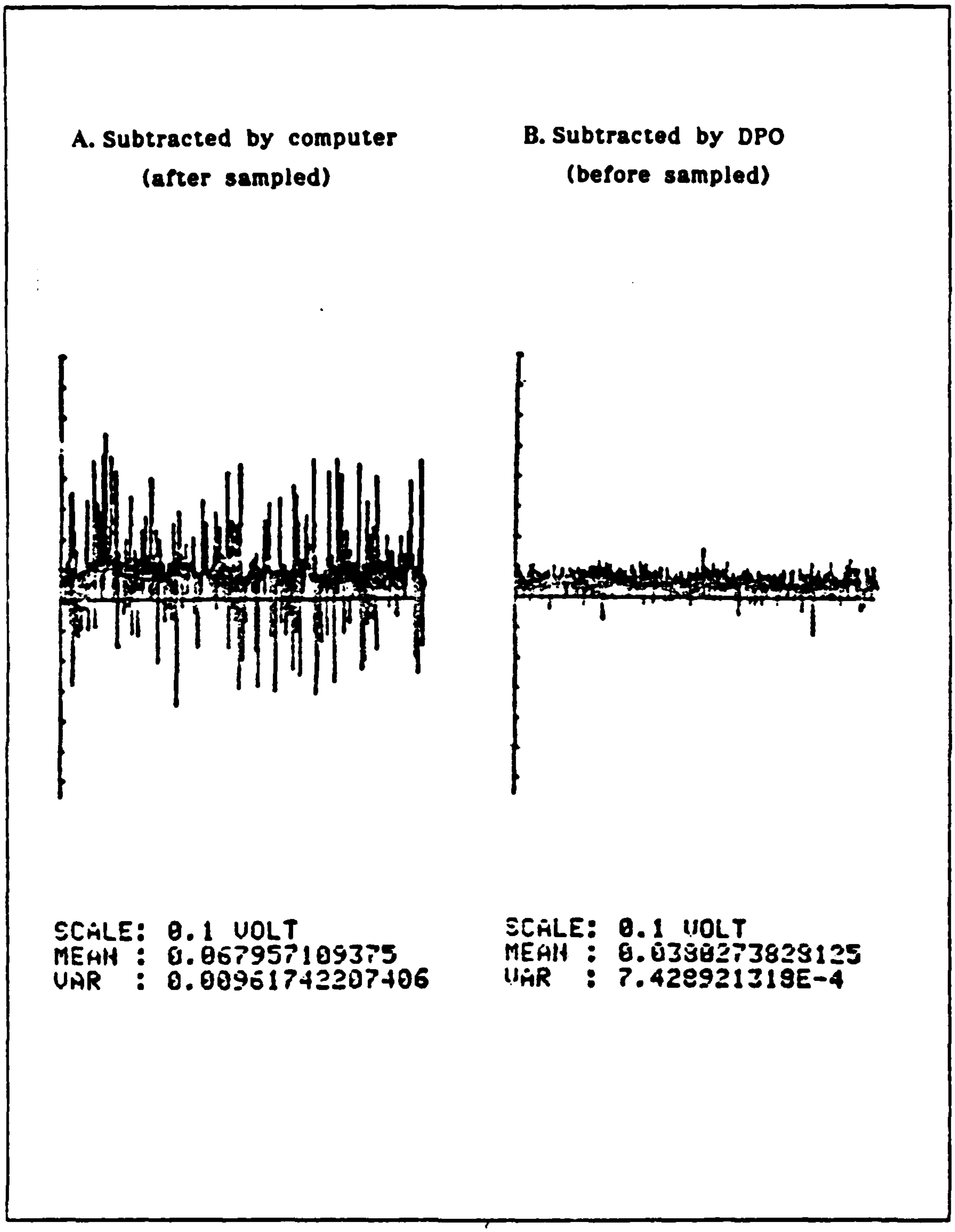


Figure 5. Simultaneous Channel Sampling Test by Subtraction

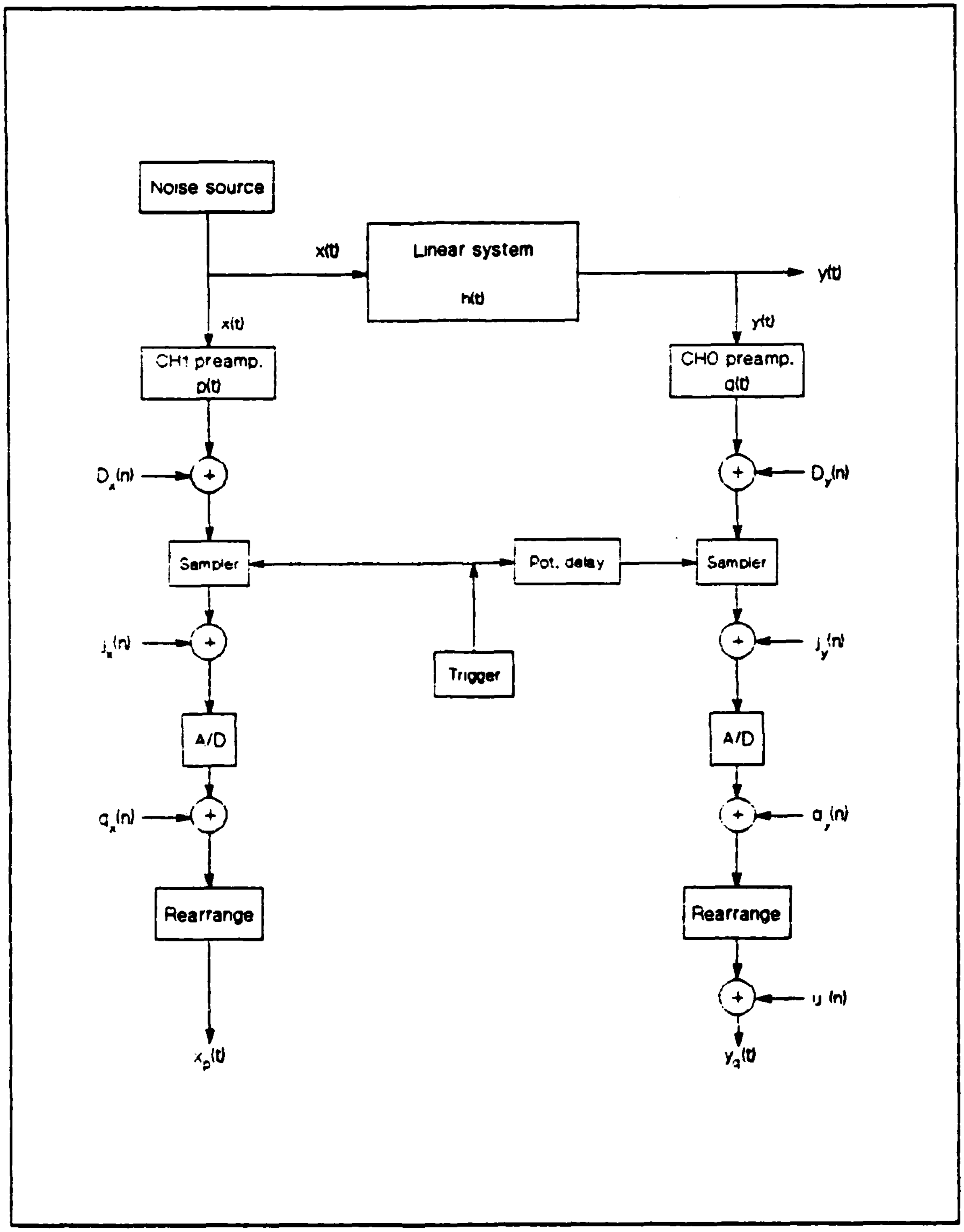


Figure 6. A Detailed Model of The Sampling System of the DPO

Let a subtracted sequence be denoted as

$$Z(n) \equiv X_p(kL) - Y_q(kL + n) \tag{2.13}$$

where *"n"* is due to the time-shift. Then the mean-square of $Z(n)$ is described as

$$\begin{aligned}
\overline{[\, Z(n)\,]^2} &= \overline{[\, X_p(kL) - Y_q(kL+n)\,]^2} \\
&= \overline{[\{\, X(kL) + D_x(kL) + n_x(kL)\,\} - \{\, Y(kL+n) + D_y(kL+n) + n_y(kL+n)\,\}]^2} \\
&= \text{DC term} - 2\dot{R}_{xy}(n) \\
&= \overline{[\, Z(\infty)\,]^2} - 2\hat{R}_{xy}(n)
\end{aligned}$$

where we have assumed stationarity of the random process in X and Y. Therefore, the desired estimation of the crosscorrelation function is

$$\dot{R}_{xy}(n) = \frac{1}{2}\,[\,\overline{[\, Z(\infty)\,]^2} - \overline{[\, Z(n)\,]^2}\,] \tag{2.14}$$

The results of the trial measurements reveal that this estimate has a better and more consistent value than the result from method 2. This measurement technique has been used for this research.

C. PROPERTIES OF THE ESTIMATED CROSSCORRELATION

Since the crosscorrelation function has an important role in the analysis of linear systems with random inputs, an important practical problem is that of determining the quality of the estimation of the function for experimentally observed random processes. In order to evaluate the quality of this estimate it is necessary to determine the mean and the variance of $R_{xy}(n)$, since the estimated crosscorrelation is a random variable whose precise value depends upon the particular sample function being used and the particular set of samples taken. The mean value for Equation (2.8) and (2.14) can be computed as follows:

$$
\begin{aligned}
E[\hat{R}_{xy}(n)] &= E\left[\ \frac{1}{K}\sum_{k=0}^{K-1} X(kL)\ Y(kL+n)\ \right] \\
&= \frac{1}{K}\sum_{k=0}^{k-1} E[\ X(kL)\ Y(kL+n)\ ] \\
&= \frac{1}{K}\ K\, R_{xy}(n)
\end{aligned}
$$

$$
E[\hat{R}_{xy}(n)] = R_{xy}(n) \tag{2.15}
$$

Thus, the expected value of the estimate is the true value of the crosscorrelation function and is an unbiased estimate of the crosscorrelation function. The variance is denoted as

$$
\begin{aligned}
Var[\ \hat{R}_{xy}(n)\ ] &= E[\ \{\hat{R}_{xy}(n) - R_{xy}(n)\}^2\ ] \\
&= E[\ \{\hat{R}_{xy}(n)\}^2\ ] - 2E[\ \hat{R}_{xy}(n)\ R_{xy}(n)\ ] + E[\ \{R_{xy}(n)\}^2\ ] \\
&= E[\ \{\hat{R}_{xy}(n)\}^2\ ] - \{\ R_{xy}(n)\ \}^2 \\
&= E[\ \{\ \frac{1}{K}\sum_{k=0}^{K-1} X(kL)Y(kL+n)\ \}^2\ ] - \{R_{xy}(n)\ \}^2
\end{aligned}
$$

$$
\begin{aligned}
Var[\ \hat{R}_{xy}(n)\ ] = \frac{1}{K^2}\sum_{j=0}^{K-1}\sum_{k=0}^{K-1} & E[\{\ X(jL)Y(jL+n)\ \}\ \{\ X(kL)Y(kL+n)\ \}\ ] \\
& - \{\ R_{xy}(n)\ \}^2
\end{aligned} \tag{2.16}
$$

Since j and k are different samples in the ensemble space, it is reasonable to assume that they are statistically independent random variables when $j \neq k$. Hence, Equation (2.16) becomes

$$
\begin{aligned}
E[\{\ X(jL)Y(jL+n)\ \}\ \{\ X(kL)Y(kL+n)\ \}\ ] = E[\{\ X(KL)Y(kL+n)\ \}^2\ ] &\qquad ,\ j = k \\
\equiv R_{x^2y^2}(n) & \\
\equiv A &
\end{aligned}
$$

$$E[\{X(jL)Y(jL+n)\}\{X(kL)Y(kL+n)\}] = \{E[X(kL)Y(kL+n)]\}^2 \qquad , j \neq k$$
$$\equiv \{R_{xy}(n)\}^2$$
$$\equiv B$$

where A is the crosscorrelation of X^2 and Y^2 while B is the square of the crosscorrelation for X and Y. Using this result, the variance leads to

$$Var[\hat{R}_{xy}(n)] = \frac{1}{K}[KA + (K^2 - K)B^2] - B^2$$
$$= \frac{A - B^2}{K}$$

$$Var[\hat{R}_{xy}(n)] = \frac{1}{K}\sigma^2_{xy}(n) \tag{2.17}$$

where $\sigma^2_{xy}(n)$ is the true variance of the product of the random variables X, and Y_{n+r}.

An interesting phenomena takes place when the time goes to infinity. In this case, if $X(n)$ and $Y(n)$ are zero mean random variables, then

$$R_{x^2y^2}(\infty) = \overline{X^2}\,\overline{Y^2}$$
$$R_{xy}(\infty) = 0$$

Therefore,

$$Var[\hat{R}_{xy}(\infty)] = \frac{\overline{X^2}\,\overline{Y^2}}{K} \tag{2.18}$$

This means that the variance of the measured crosscorrelation approaches a constant value as the time separation goes to infinity. Therefore, the resultant estimated crosscorrelation could be thought of as

$$\hat{R}_{xy}(n) = R_{xy}(n) + \frac{\sigma^2_{xy}(n)}{K}\theta(n) \tag{2.19}$$

where, $\theta(n)$ is the estimation error with unit variance. However, this effect can be reduced by increasing the number of sample points, since the variance is normalized by this number.

D. SYSTEM IDENTIFICATION USING ESTIMATED CROSSCORRELATION FUNCTION.

To measure the input and output noise, some kind of measuring device must be used. Therefore it would be reasonable to think that the measured sequence results from a convolution of the sequence to be measured and the system response of the measuring device. This is illustrated in Figure 7. Therefore, the measured crosscorrelation function is $R_{x_p y_q}(t)$ rather than $R_{xy}(t)$.

$$R_{x_p y_q}(t) \equiv \int_{-\infty}^{\infty} x_p(\tau) y_q(\tau + t)\, d\tau \tag{2.20}$$

where,

$$\begin{aligned} X_p(\tau) &\equiv \int_{-\infty}^{\infty} p(\sigma) X(\tau - \sigma)\, d\sigma \\ &= p(\tau) * X(\tau) \end{aligned} \tag{2.21}$$

$$\begin{aligned} Y_q(\tau) &\equiv \int_{-\infty}^{\infty} q(\mu) Y(\tau - \mu)\, d\mu \\ &= q(\tau) * Y(\tau) \end{aligned} \tag{2.22}$$

Substituting Equations (2.21) and (2.22) into Equation (2.20) yields

$$\begin{aligned} R_{x_p y_q}(t) &= \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} p(\sigma) x(\tau - \sigma)\, d\sigma \int_{-\infty}^{\infty} q(\mu) y(\tau + t - \mu)\, d\mu d\tau \\ &= \int_{-\infty}^{\infty} p(\sigma) \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} x(\tau - \sigma) y(\tau + t - \mu)\, d\tau\, q(\mu)\, d\mu d\sigma \\ &= \int_{-\infty}^{\infty} p(\sigma) \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} x(\alpha) y((t + \sigma - \mu) + \alpha)\, d\alpha\, q(\mu)\, d\mu d\sigma \end{aligned}$$

$$R_{x_p y_q}(t) = \int_{-\infty}^{\infty} p(\sigma) \int_{-\infty}^{\infty} R_{xy}(t + \sigma - \mu) q(\mu)\, d\mu d\sigma \tag{2.23}$$

Since the inner integral of the right expression in Equation (2.23) is the convolution between $R_{xy}(\mu)$ and $q(\mu)$, the equation can also be denoted as follows.

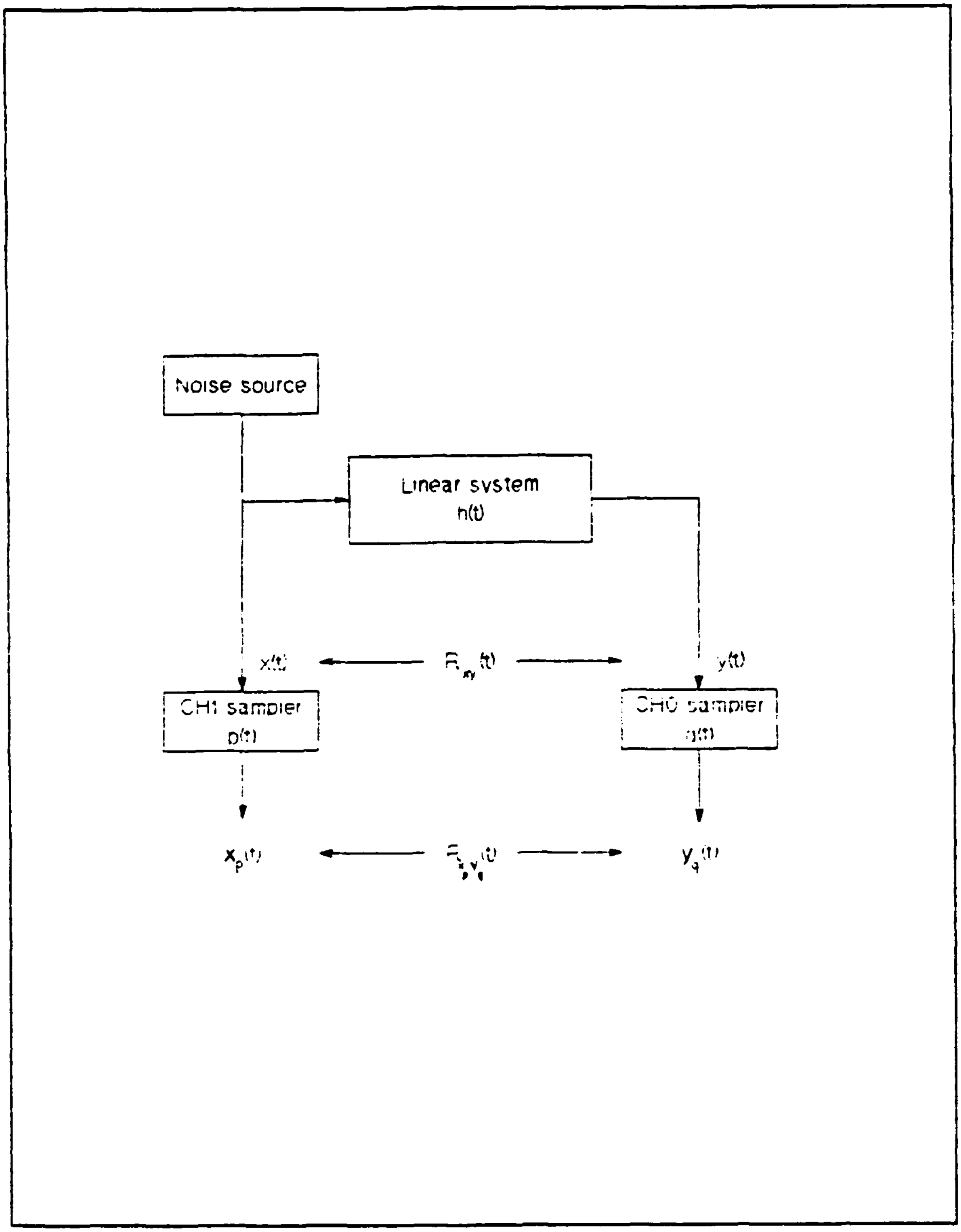


Figure 7. A Detailed System Model to be Measured

$$
\begin{aligned}
R_{x_p y_q}(t) &= \int_{-\infty}^{\infty} p(\sigma) \int_{-\infty}^{\infty} q(t+\sigma-\mu) R_{xy}(\mu)\, d\mu d\sigma \\
&= \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} p(\sigma) q((t-\mu)+\sigma)\, d\sigma\, R_{xy}(\mu)\, d\mu \\
&= \int_{-\infty}^{\infty} R_{pq}(t-\mu) R_{xy}(\mu)\, d\mu
\end{aligned} \tag{2.24}
$$

Therefore, the resultant measured crosscorrelation is

$$
\begin{aligned}
R_{x_p y_q}(t) &= R_{pq}(t) * R_{xy}(t) \\
&= R_{pq}(t) * R_x(t) * h(t) \\
&= R_{x_p x_q}(t) * h(t)
\end{aligned} \tag{2.25}
$$

where $R_{x_p x_q}(t)$ is referred to as the system crosscorrelation in this thesis and has the same role as the autocorrelation in Equation (2.3).

Since the measurement of the system crosscorrelation is performed without the target, it should be an even function if the responses of the two sampling systems of the DPO are exactly the same. In fact, the responses of the two channels do not have exactly the same characteristics so the test result of the measured system crosscorrelation has an almost even shape, as expected. This will be described in chapter 4.

The Fourier transform of Equation (2.25) results in

$$
\begin{aligned}
S_{x_p y_q}(f) &= S_{pq}(f)\, S_{xy}(f) \\
&= S_{pq}(f)\, S_x(f)\, H(f) \\
&= S_{x_p x_q}(f)\, H(f)
\end{aligned} \tag{2.26}
$$

which satisfies the crosscorrelation theorem.

To get the impulse response, $R_{x_p y_q}(t)$ must be deconvolved by $R_{x_p x_q}(t)$. Therefore at least two measurements must be performed for doing time deconvolution:

$$
\hat{R}_{x_p x_q}(n) = \hat{R}_{pq}(n) * \hat{R}_x(n) \tag{2.27}
$$

$$
\hat{R}_{x_p y_q}(n) = \hat{R}_{pq}(n) * \hat{R}_x(n) * \hat{h}(n) \tag{2.28}
$$

The power spectrums of Equations (2.27,28) are

$$\grave{S}_{x_p x_q}(k) = \hat{\hat{S}}_{pq}(k)\, \hat{S}_x(k) \tag{2.29}$$

$$\grave{S}_{x_p y_q}(k) = \hat{\hat{S}}_{pq}(k)\, \hat{S}_x(k)\, \hat{H}(n) \tag{2.30}$$

Then, the frequency response of the system is extracted by dividing Equation (2.30) by Equation (2.29).

$$\begin{aligned} \dot{H}(k) &= \frac{\grave{S}_{x_p y_q}(k)}{\grave{S}_{x_p x_q}(k)} \\ &= \frac{\hat{\hat{S}}_{pq}(k)\, \hat{S}_x(k)\, \hat{H}(k)}{\hat{\hat{S}}_{pq}(k)\, \hat{S}_x(k)} \end{aligned} \tag{2.31}$$

However, this frequency division must be compensated since the estimated cross-correlation function is corrupted by noise, as described in Equation (2.19), so that the power spectral density is biased by the noise power. The technique used here for noise compensation is known as Riad's Method. The "optimal estimator" prescribed by Riad's Method [Ref. 10] is

$$\hat{H}(k) = \frac{\hat{S}_{x_p y_q}(k)\, \hat{S}^{*}_{x_p x_q}(k)}{|\hat{S}_{x_p x_q}(k)|^2 + \lambda W_x} \tag{2.32}$$

where W_x represents the average spectral power density of the system crosscorrelation function:

$$W_x = \frac{1}{K} \sum_{k=0}^{K-1} \hat{S}^2_{x_p y_q}(k) \tag{2.33}$$

The parameter λ is denoted as the smoothing parameter and establishes the lower limit of the denominator, hence reducing the noise effect on the computed target response when the input signal spectrum is small. The impulse response is derived by performing an inverse Fourier transform on the target frequency response

$$\hat{h}(n) = F^{-1}\{ \hat{H}(k) \} \quad (2.34)$$

Another important point to keep in mind is that we use an FFT algorithm which has quite different properties from the continuous Fourier transform. Ordinarily, when the FFT is used to estimate the frequency response, windowing is performed to smooth the result. However, applying a window interferes with the circular convolution property. Therefore, in this research, we will not apply windowing before performing the FFT algorithm. Instead of windowing, the crosscorrelation function $\hat{R}_{x_p y_q}(n)$ will be "zero padded" to avoid the wrap-around problem which comes from the circular convolution property.

III. BASIC EXPERIMENTAL CONFIGURATION

A. DESCRIPTION OF DPO AND ITS MODIFICATION

To meet the goals of this thesis work, an ultra wide band noise source and a dual channel sampling device with high sampling rate and precise synchronization must be used. A dual channel synchronous sampling Digital Processing Oscilloscope (DPO) and a broadband noise signal generator were used for this purpose.

The DPO is not an ideal sampling device since it does not sample at a rate exceeding the Nyquist frequency. Even though the sampling rate of the DPO is measured in MHz, it can display a periodic repetitive signal having up to 12 GHz in bandwidth by rearranging the actual low rate sampled data using a display buffer. Hence the signal displayed on the oscilloscope looks like it has been sampled at over the Nyquist rate. The sampling technique of the Tektronix DPO sampler S-6 is illustrated in Figure 8. The Tektronix S-52 pulse generator produces a fast repetitive pulse train. A time limited output of a lumped network can be displayed at an apparent sampling rate exceeding the Nyquist rate by using the S-52 to drive the network. This is shown in Figure 9.

However, this property could not be extended to a non-repetitive signal since the technique does not reconstruct the original shape of the actual sequence by rearranging the sampled data after it is taken by the sampling head. Consequently, we could not utilize the virtual characteristics of repetitive sampling of the DPO for this research. The broad band noise generator has about 13 GHz bandwidth which is far beyond the single shot sampling rate of the DPO.

Using the measurement method 2, as described in Section II.B, one of the signals to be measured is manually shifted through the required sampling interval. The measurement process treats the data as samples of an ensemble space rather than a time sequence since our intention is to compute the value of the crosscorrelation of the shifted time difference. Under this condition, there is no restriction of the sampling rate and the DPO can be used. There is, however, the need of an additional variable delay function on one channel to make the required time shift. This function is carried out using the "Delay" knob on the channel 0 sampler.

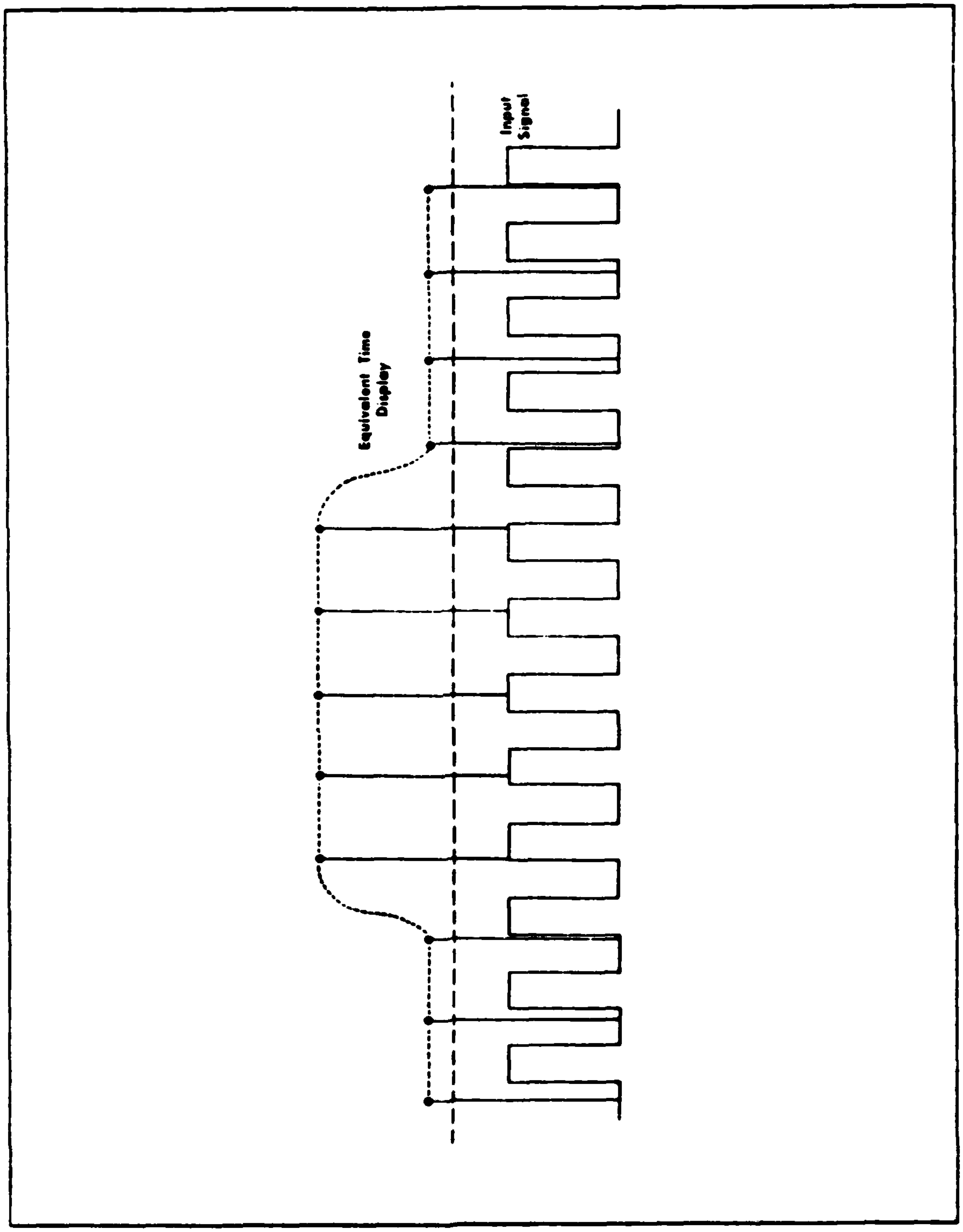
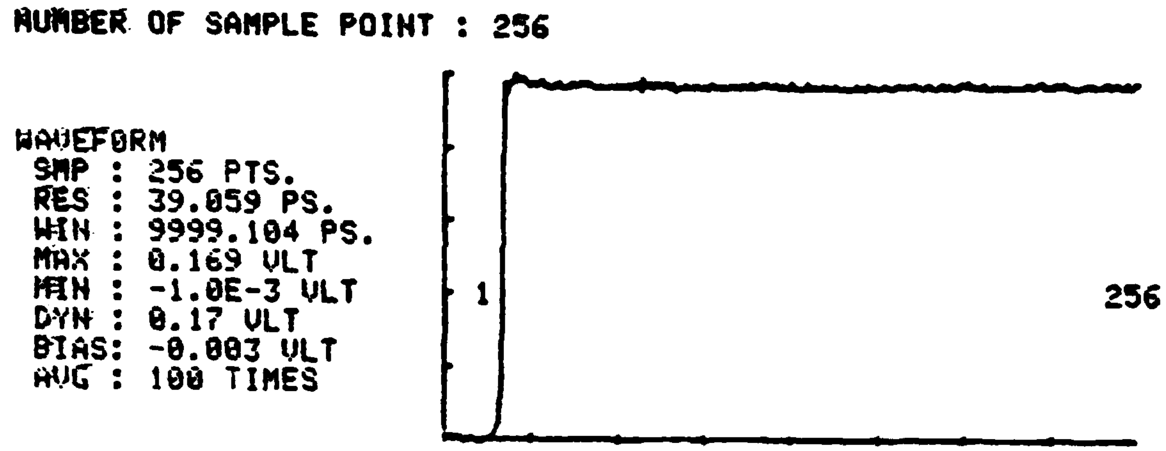


Figure 8. The Sampling Scheme of the Tectronix 7854 DPO

A. A portion of a rectangular pulse produced by the S-52 pulse generator



B. Modified pulse filtered by the DMR005 bandpass amplifier

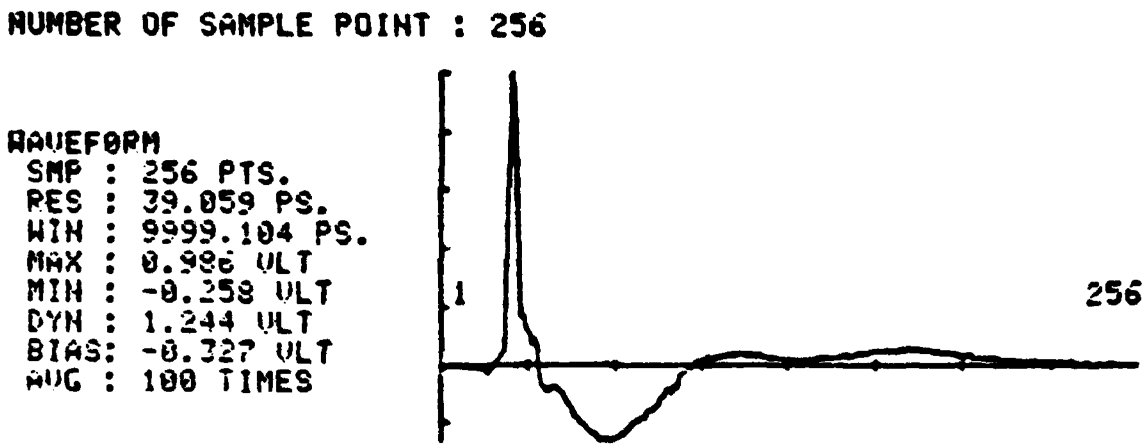


Figure 9. A Pulse Signal and Its Convolved Output by a Linear System

This delay knob has a 10 nanosecond delay range which is enough for measuring the crosscorrelation function for the small targets that are used. Assuming that the bandwidth of the sampled signal is less than 12 GHz, the required sampling interval is

$$T_s = \frac{1}{f_s} = 40 \text{ psec} \tag{3.1}$$

where, according to the sampling theorem,

$$f_s = 2B = 25 \text{ GHz} \tag{3.2}$$

To obtain this type of resolution on the delay, a 10 turn potentiometer was used instead of the built-in one turn potentiometer on the 10 nanosecond delay knob. This potentiometer has a five thousand division scale on its face within the full range of its delay. This modification is illustrated in Figure 10.

During the laboratory measurements, it was found that the actual time delay was not exactly linearly proportional to the delay reading. A potentiometer reading table was then used to mark the value of the reading corresponding to each time delay. A sample potentiometer reading table is shown in Figure 11. Although the actual delay is dependent upon the potentiometer reading table used with each measurement, a reading difference of about 3.0 represents approximately a 40 picosecond delay.

To create a potentiometer reading table, an additional measurement using the pulse source was performed prior to the noise-source measurement. After creating several such tables, it was revealed that the potentiometer reading has about $\pm$ 3 picosecond reading error due to misreading and the line-width of the displayed pulse when it is performed on 20 picosecond per division time scale. This is illustrated in Figure 12. One factor which increases this line-width is the jitter noise. This reading error increases as the time scale increases and makes the potentiometer reading table next to useless. Therefore, a linear increment of the potentiometer by 1.5 is usually acceptable if the total time window to be measured is over 200 picoseconds. In such a case the measurement can be performed using a 20 picosecond per division time scale.

Another problem encountered during the laboratory work is a scaling difference of the sampling interval of the two channels as well as the drift of the sampling frame. A comparision of $(X - Y)$ on the 20 psec./div. and 10 nsec./div. is shown in Figure 13.

Looking at Figure 13, we see that the upper part has noise with a constant envelope while the other demonstrates a noise with a consistently growing envelope. Therefore,

it would be reasonable to think that the source of the noise in the upper figure comes from the jitter noise of the two channels due to the random sampling time error while the other includes the jitter noise and a scaling difference of the sampling interval. One possible source of the scaling problem might be come from machine accuracy. So, if the two signals are aligned at one position using the potentiometer delay knob, so that the subtracted signal at the point shows a minimum envelope, then the error caused by different sampling rates grows with increasing the time differences from the aligned point, producing larger error in the envelope. Therefore, it would be better to sample the data on a 20 picosecond per division (nominal value) to minimize problems introduced by the difference of sampling rates.

During the laboratory work it was found that the images of a pulse signal as displayed on each of the two channels was gradually drifting from left to right with differing velocity. This drift problem might come from the thermal inconsistency of the DPO since it can be reduced by warming up for about one hour. However, the effect still remains. This problem requires completion of the experiment in as short a time as possible.

B. NOISE SOURCE GENERATOR HARDWARE AND ITS DEVELOPMENT

A model DMR-005 broadband noise generator was used for this research. This noise source includes a noise generator and two cascaded broadband amplifiers, each of which has about 20 dB gain with a 13 GHz bandwidth. The system output is approximately 400 mV in rms value and the voltage histogram resembles a Gaussian distribution. The block diagram, the frequency characteristic, and a sample recorded output of the noise source are illustrated in Figures 14, 15, and 16.

In the laboratory it was found that a frequent change of the physical environment may lead to electrical inconsistency resulting in output fluctuations. A little after beginning this research, one of the two amplifiers used in the noise source failed and it was sent to the manufacturer to fix the malfunction. After the amplifier was returned to NPS, an aluminum support was attached to the noise source to avoid further problems. The support also acts as a heat sink. Thereafter, a consistent noise output has been produced.

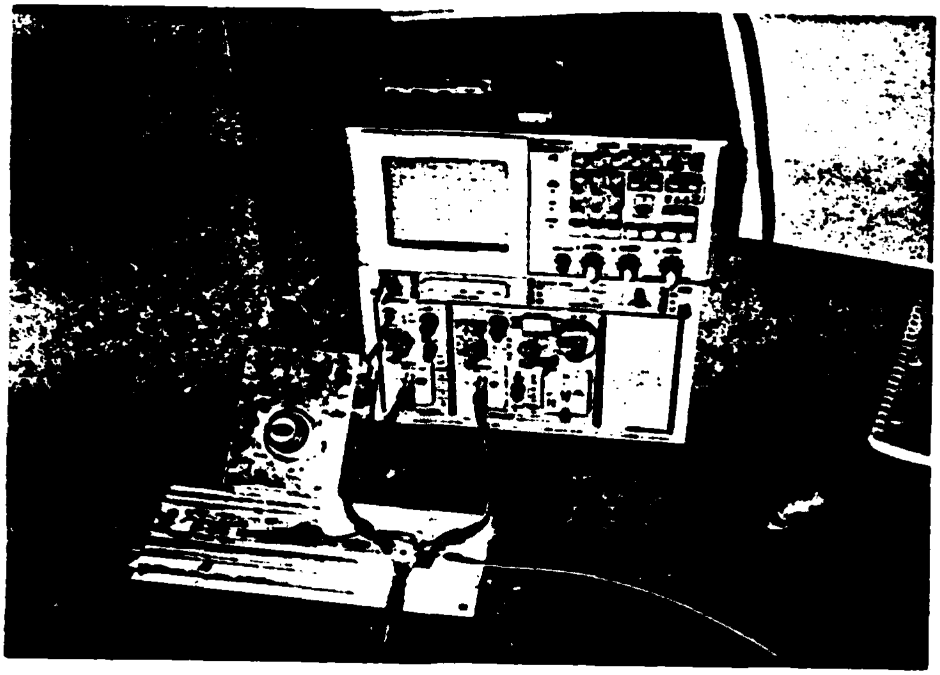


Figure 10. Modified Tektronix 7854 DPO

POTENTIOMETER READING TABLE

Test I.D. ______________ Date

Number of meas. ______________

Number of samples ______________ File number

Meas No.	Seq No.	Delay (psec)	Pot. Reading	Remark	Meas No.	Seq No.	Delay (psec)	P R
1			.		33			
2			.		34			
3			.		35			
4			.		36			
5			.		37			
6			.		38			
7			.		39			
8			.		40			
9			.		41			
10			.		42			
11			.		43			
12			.		44			
13			.		45			
14			.		46			
15			.		47			
16			.		48			
17			.		49			
18			.		50			
19			.		51			
20			.		52			
21			.		53			
22			.		54			

Figure 11. Potentiometer Reading Table

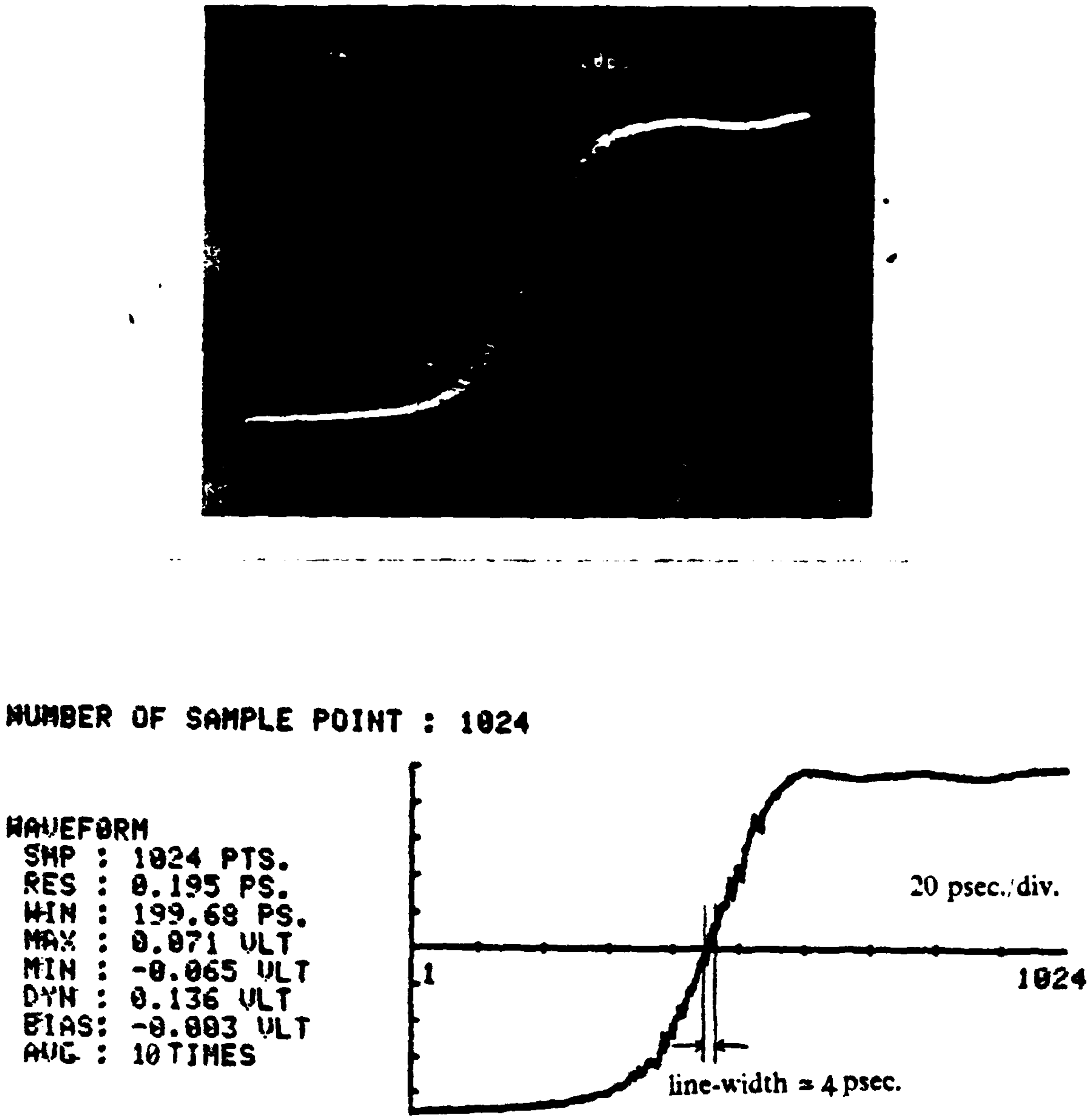
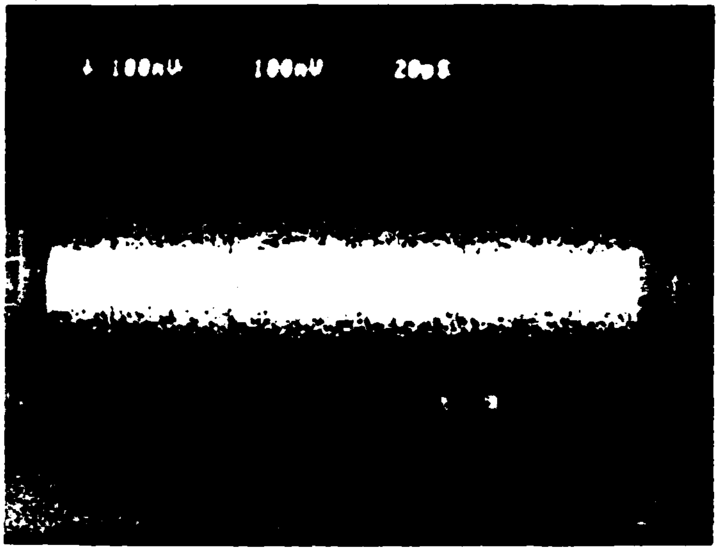


Figure 12. The Reading Error Due to the Line-width of Ramp Signal

A. $(X - Y)$ displayed on the 20 psec./div. window



B. $(X - Y)$ displayed on the 10 nsec./div. window

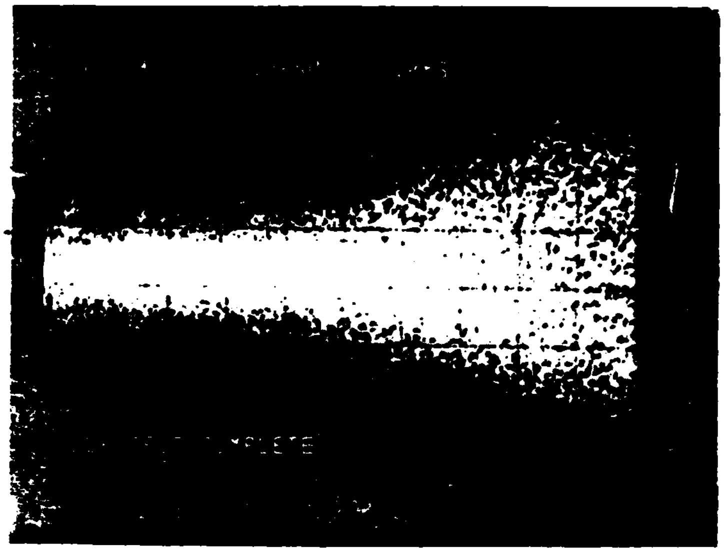


Figure 13. The Effect of the Difference of Sampling Interval

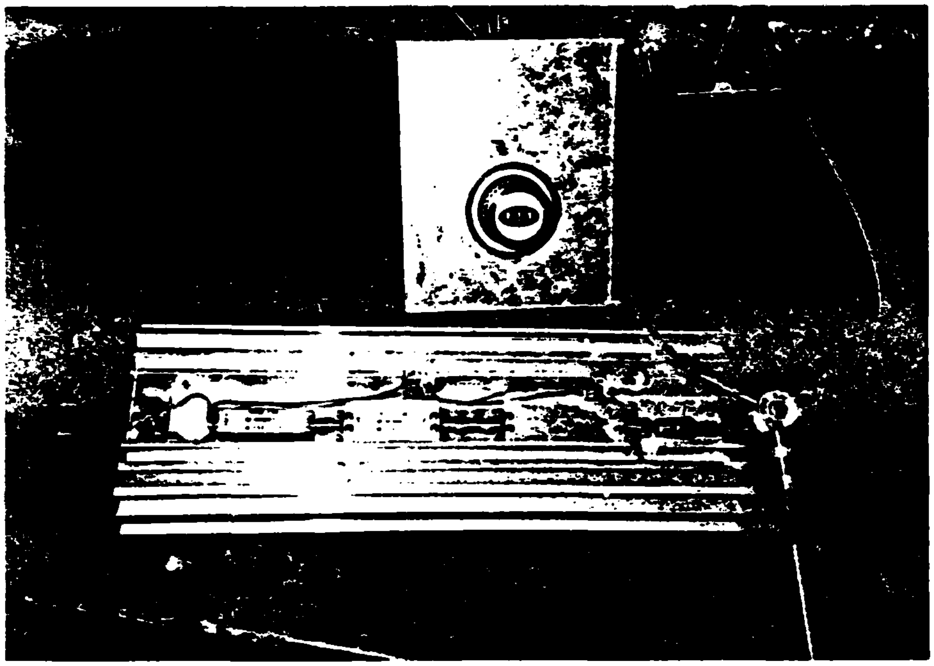


Figure 14. Noise Generator

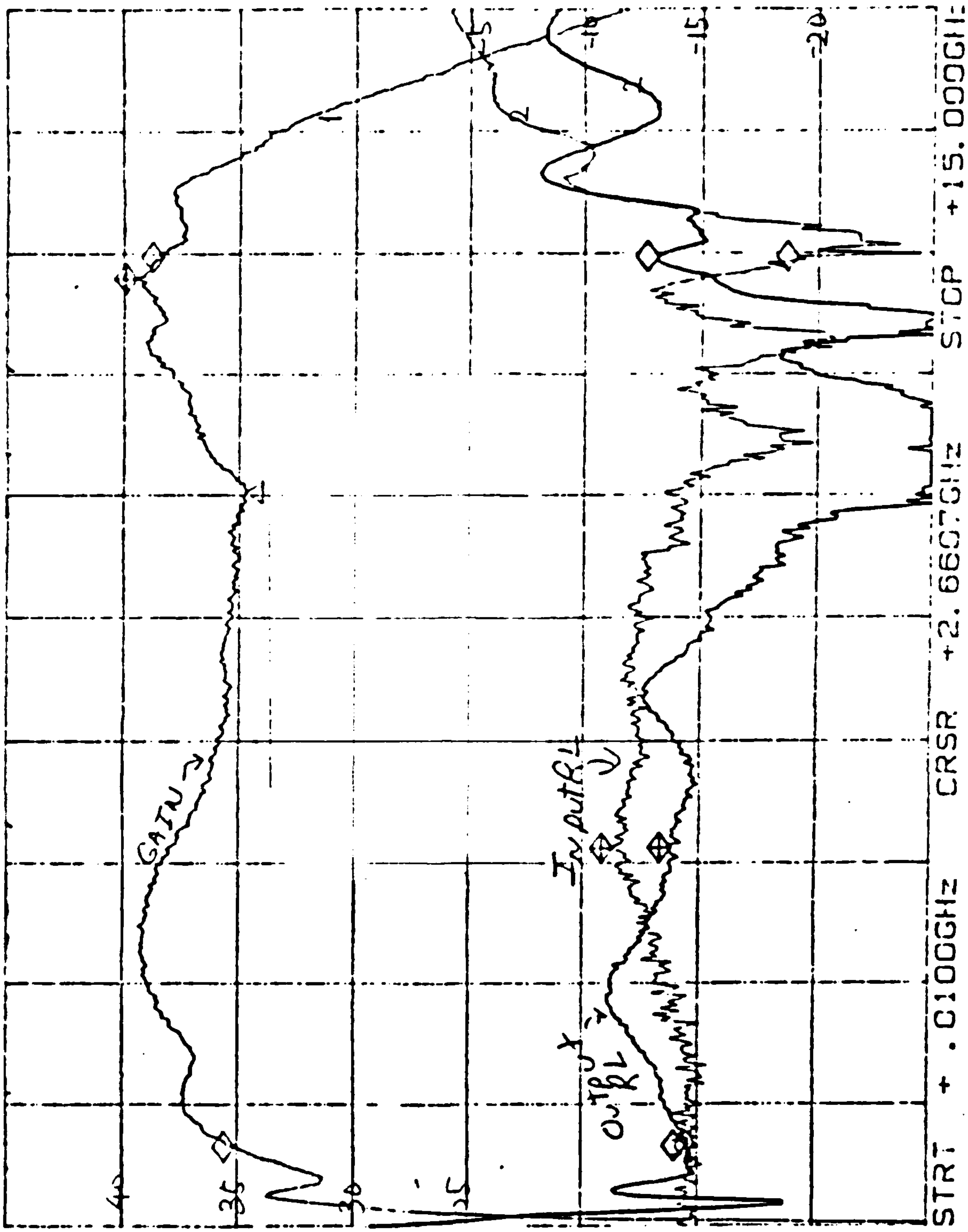


Figure 15. Frequency Response of an Amplifier of the Noise Generator

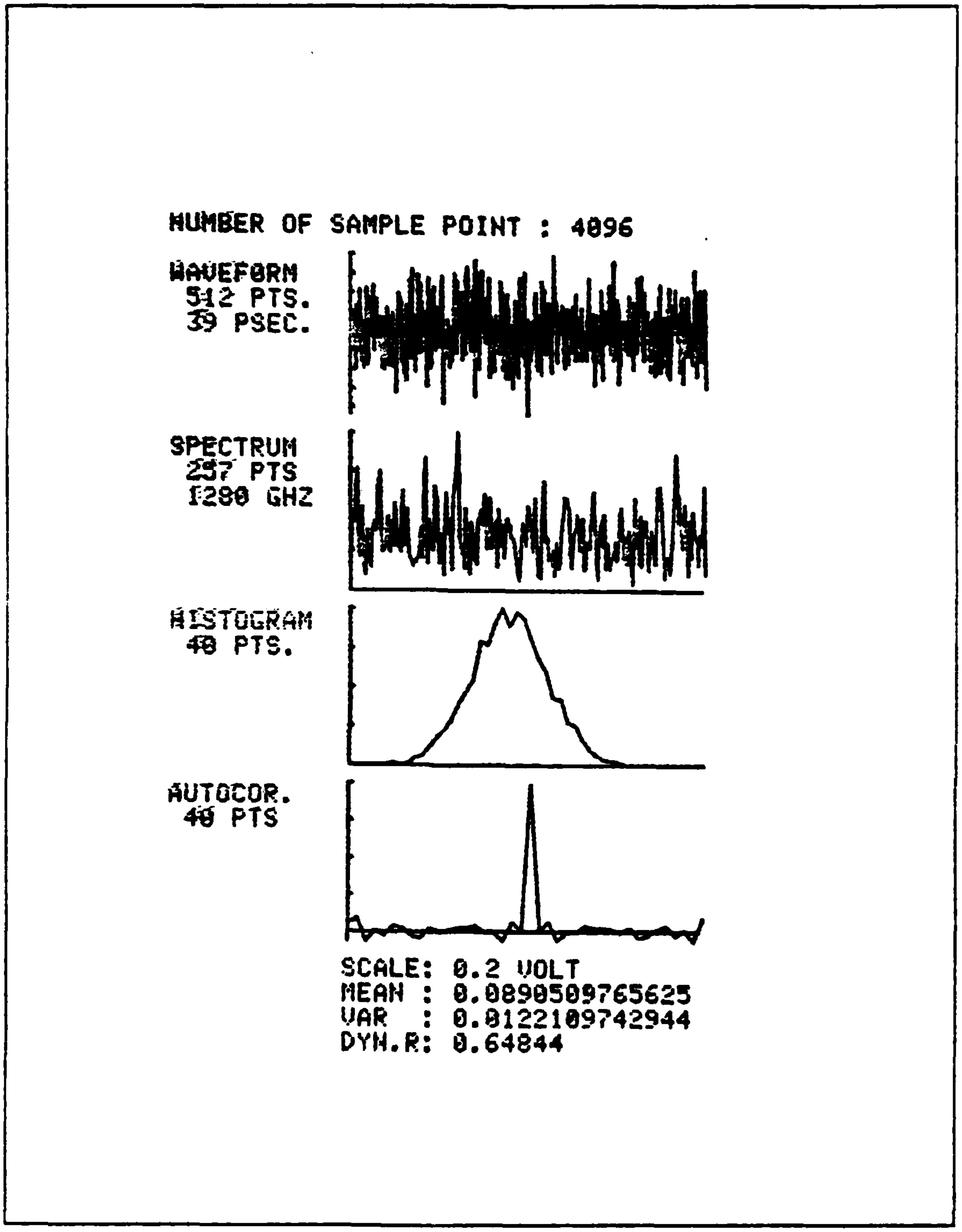


Figure 16. A Recorded Noise Signal

C. SUMMARY OF THE PROBLEMS AND SOLUTIONS FOR THE CROSSCORRELATION MEASUREMENT

The problems for the crosscorrelation measurement and the solutions described so far are summarized as follows.

1. To produce a noise source with consistent characteristics, an aluminum heat sink support was attached to the noise source.
2. A sampling rate lower than the Nyquist frequency and mispositioning of the noise added to the channel 0 (output measurement channel) forced use of the measurement method 3.
3. The scaling difference of the sampling period of the two channels leads to sampling the data on the 20 picosecond per division time scale to minimize the effect.
4. The drift of sampling frame requires a warm up period of at least one hour to reach thermal steady state and then to perform the measurement as fast as possible.
5. To perform the fastest measurement, a 1.5 reading difference of the potentiometer is linearly increased regardless of potentiometer reading table since the experiment reveals that a 1.5 reading difference of the potentiometer makes a 20 picosecond delay with affordable error which can be compromised with machine precision and visual reading error.
6. Also, it is recommended to perform the experiment as quickly as possible to reduce the data transfer time, which is proportional to the number of the samples. (It takes about 8.5 second for transferring a set of 1024 samples of data.)

Following these guidelines, about half an hour of measurement time is needed for 64 point by 2 sets of 1024 samples with an additional one hour for warming up the system, which will be the best condition for the crosscorrelation measurement under the current laboratory environment. However, the drift problem still remains since at least one-half hour is needed to perform the experiment.

Finally, detailed tests revealed that the system crosscorrelation at the peak point has the value of about twenty times the peak-to-peak value of the error noise. This is illustrated in Figure 17. Therefore, if the value of the original crosscorrelation drops down significantly, then the error noise will dominate the measured signal and will make the crosscorrelation method impossible to use.

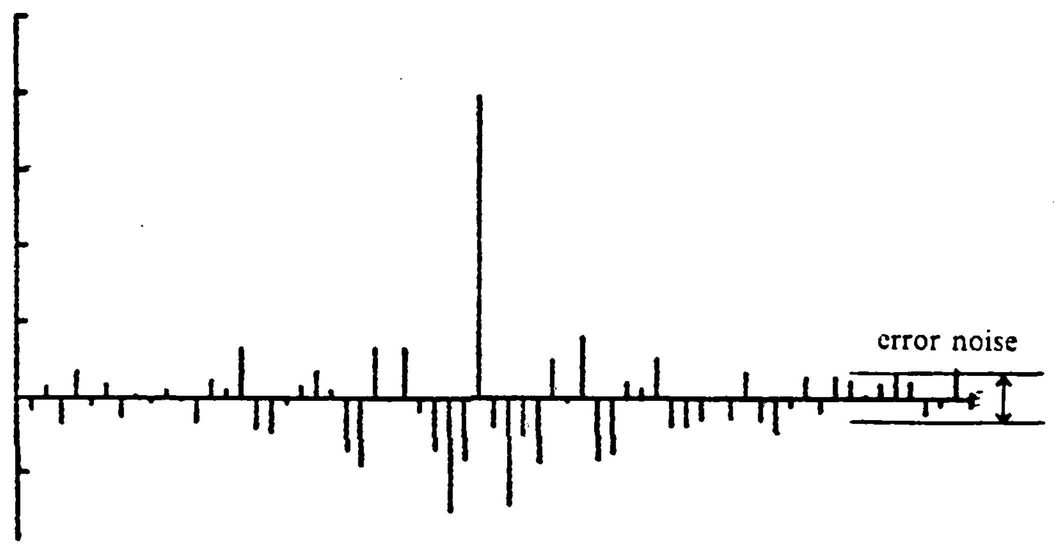


Figure 17. The Amount of the Measured Error Noise

IV. CALIBRATION AND VALIDATION MEASUREMENT

A. INITIAL TEST OF SIMULTANEOUS CHANNEL SAMPLING

The most important and critical role of the DPO in this research is in simultaneously sampling a pair of time functions which are probed at the input and the output port of a linear system. A useful validation test for the simultaneous sampling characteristic is to subtract the signal from one channel (X : input sequence in this thesis) from the other channel (Y : output sequence). This will be displayed on the DPO screen by using the built in "Add" and "Inverse" functions of the DPO. Using the manual delay knob, the image of the subtracted signal can be minimized using the simultaneous sampling position. The potentiometer reading at this point (it must be the $n = 0$ point of the system crosscorrelation, $\hat{R}_{x_p x_q}(n)$) has a value of about 200 indicating that the sampling channel 0 (output channel) has a time delay of about 2.7 nanoseconds less than that of the channel 1. This is illustrated in Figure 18 with a comparison with the original input sequence.

Looking at the Figure 18, the left part shows a noise with a consistent envelope of small variance. The source of the noise on the left figure comes from the jitter noise of the two channels produced by random sampling time errors. Assuming that the envelope of the jitter noise is proportional to the time derivative of the source signal itself, the noise source signal must have more variance of its jitter noise vis-a-vis the ramp source signal. This results since the time derivative of the ramp signal produced by DPO is much smaller than that of the noise source indicating that the noise signal is more vulnerable to the jitter noise than the ramp signal. This property is verified in Figure 19.

B. CROSSCORRELATION OF THE DPO SYSTEM.

As described in Section II.D, the crosscorrelation between input and output is convolved by the crosscorrelation between the impulse response of the two sampling heads. The discrete version of eq.(2.25) is

$$
\begin{aligned}
R_{x_p y_q}(n) &= \dot{R}_{pq}(n) * \dot{R}_{xy}(n) \\
&= \dot{R}_{pq}(n) * \hat{R}_{x}(n) * \dot{h}(n) \qquad (4.1) \\
&= \dot{R}_{x_p x_q}(n) * \dot{h}(n)
\end{aligned}
$$

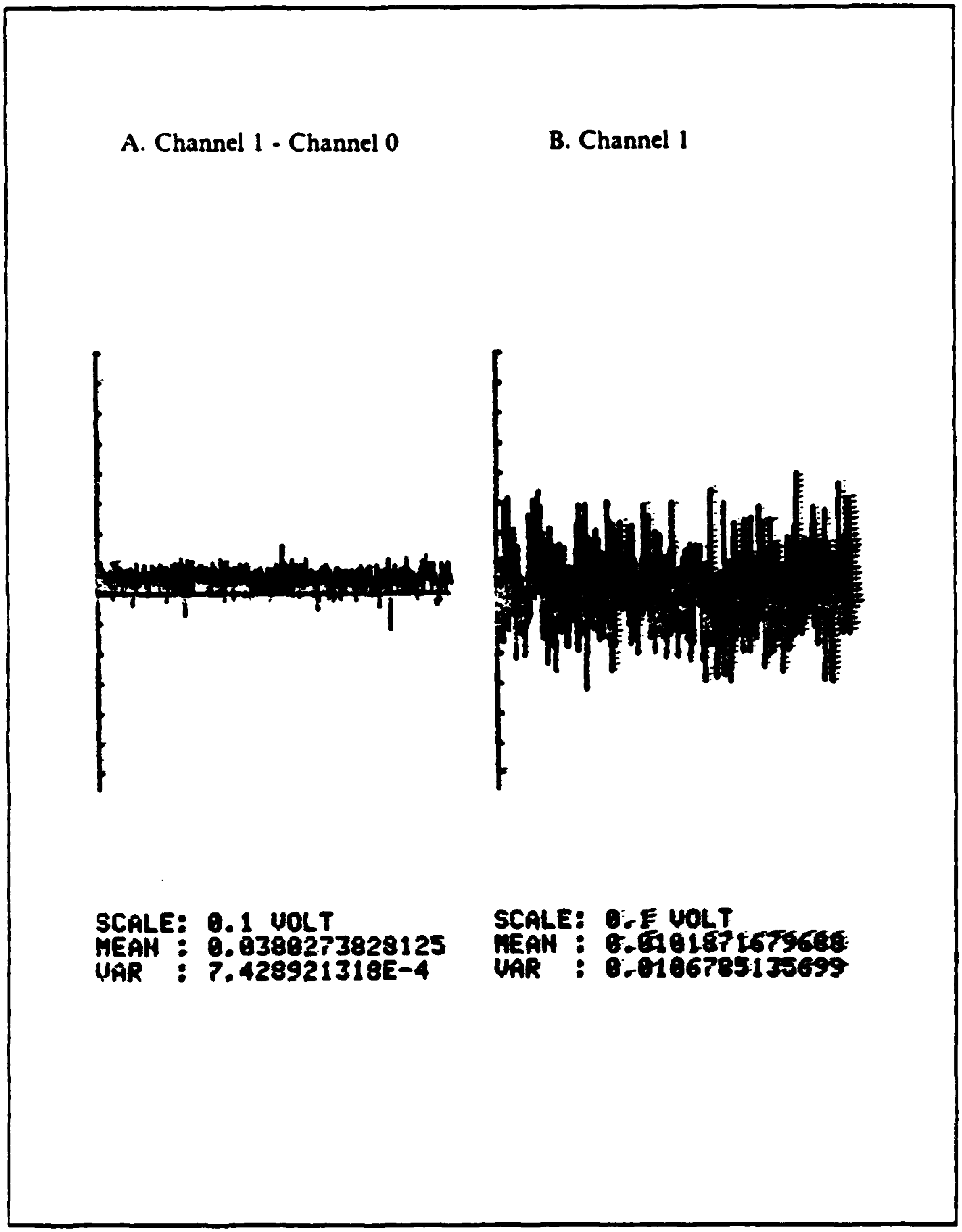
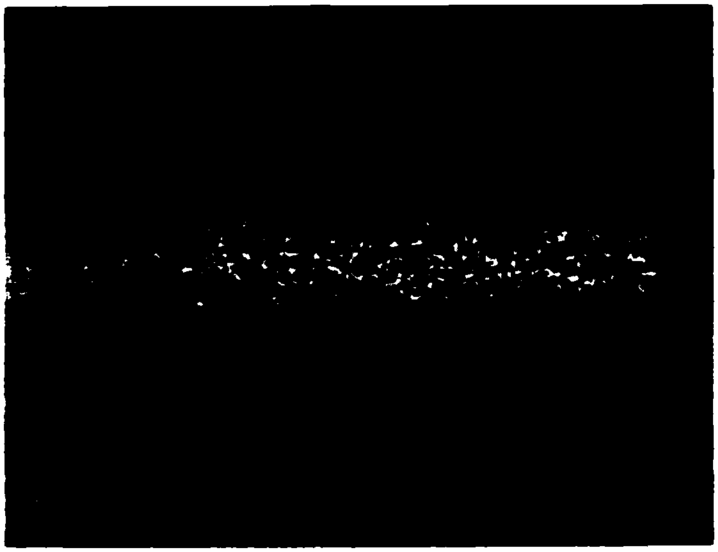


Figure 18. Simultaneous Channel Sampling Characteristics by Subtraction

A. Jitter noise of the noise signal



B. Jitter noise of the pulse signal

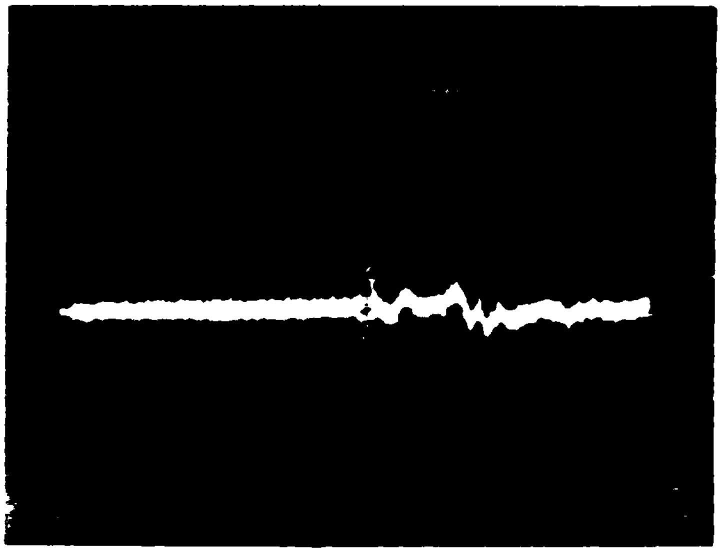


Figure 19. Jitter Noise of the Noise and the Ramp Signal by Subtraction

where,

$$\hat{R}_{x_p x_q}(n) \equiv \hat{R}_{pq}(n) * \hat{R}_x(n) \tag{4.2}$$

Here $\hat{R}_{x_p x_q}(n)$ is the estimation of the system crosscorrelation and is convolved with the crosscorrelation of the sampling head and the autocorrelation of source noise itself. To approximately measure the system crosscorrelation, we simply feed the same input signal to each sampling head, as illustrated in Figure 20.

In the ideal case, each sampler system impulse response, $p(t)$ and $q(t)$, must have the same shape, and at best the unit impulse response. Although these two impulse responses are not exactly identical, they will in reality be very close to each other. Consequently, the shape of the system crosscorrelation $\hat{R}_{x_p x_q}(n)$ is close to, but not exactly, an even function, while the autocorrelation of the source noise $\hat{R}_x(n)$ must be even.

The initial measurements were performed using a 2.5 picosecond sampling period to get a more detailed time shape of the system crosscorrelation. Subsequent measurements were performed using a 10 picosecond sampling interval to see the entire shape of the system crosscorrelation. Figure 21 and 22 show the test results. As expected, the shape of the crosscorrelation is almost even, which means the two sampling channels have similar characteristics.

C. DECONVOLUTION VALIDATION TEST

1. Test with Noise Source

An Avantek model SA83-2954 solid-state microwave amplifier was used during this validation test. This amplifier has an average gain of 42.5 dB over the band from 2 to 6 GHz and provides a 3 dB bandwidth of about 5 GHz. The spectral characteristic of the Avantek amplifier is shown in Figure 23. This amplifier is linked to two 20 dB attenuators, since it produces moderate power, to prevent any possible damage to the sampling heads which have an operating range of 5 volts peak. Figure 24 illustrates the basic setup for this test.

To extract the impulse response of the Avantek amplifier (2-port), the following three steps were followed:

1. Test without the 2-port, measure the system crosscorrelation.
2. Test with the 2-port, measure the crosscorrelation of the 2-port.
3. Perform deconvolution computation.

The system crosscorrelation measurement was performed using 64 time points having a 40 picosecond increment. This gives about a 2.5 nanosecond window, which is almost three times longer than the effective period of the system crosscorrelation. The amount of the delay time interval (40 picoseconds) is sufficiently small in this case since this gives a Nyquist frequency exceeding the bandpass frequencies of the Avantek amplifier. A plot of the measured system crosscorrelation is shown in Figure 25.

The bandpass amplifier crosscorrelation measurement was performed using the same time points and delay interval. Further, an initial delay was given to the channel 0 in the amount of 400 picoseconds to compensate for the effective delay through the Avantek amplifier. The resultant measured crosscorrelation is shown in Figure 26.

Finally, the computation of deconvolution was performed using Riad's optimal compensation technique. As described in Section II.D, this deconvolution method serves to limit the lower bound of the denominator and thus reduces the noise effect. Several computations were performed with different smoothing factors and finally the case of 0.1 was selected for the best solution. After the computation of deconvolution, the computed impulse response was moved 32 points to the right to show the best graphic interpretation. The result is illustrated in Figure 27.

2. Test with Modified Pulse Source

The same three measurement steps were performed using the time domain method described by McDaniel [Ref. 9]. The output ramp signal from the S-52 pulse generator was filtered by one of the amplifiers used with the noise generator to produce a roughly similar power spectral density at the input. This source signal has enough innate zero padding to eliminate the wrap-around problem. The test was fairly straight forward and the results are shown in Figures 28, 29, and 30.

The comparison of the two methods is given in Figure 31. These two results have almost the same shape, as is expected, aside from the time scaling difference. The crosscorrelation method uses about a 40 picosecond time interval while the time domain method samples with a period of 39 picosecond, which is fixed by the DPO spaces. Another fact is that the result from the crosscorrelation method has more error noise power than that of the pulse method. Therefore, the performance of the crosscorrelation method using the current DPO appears to produce lower quality results than that of the pulse method.

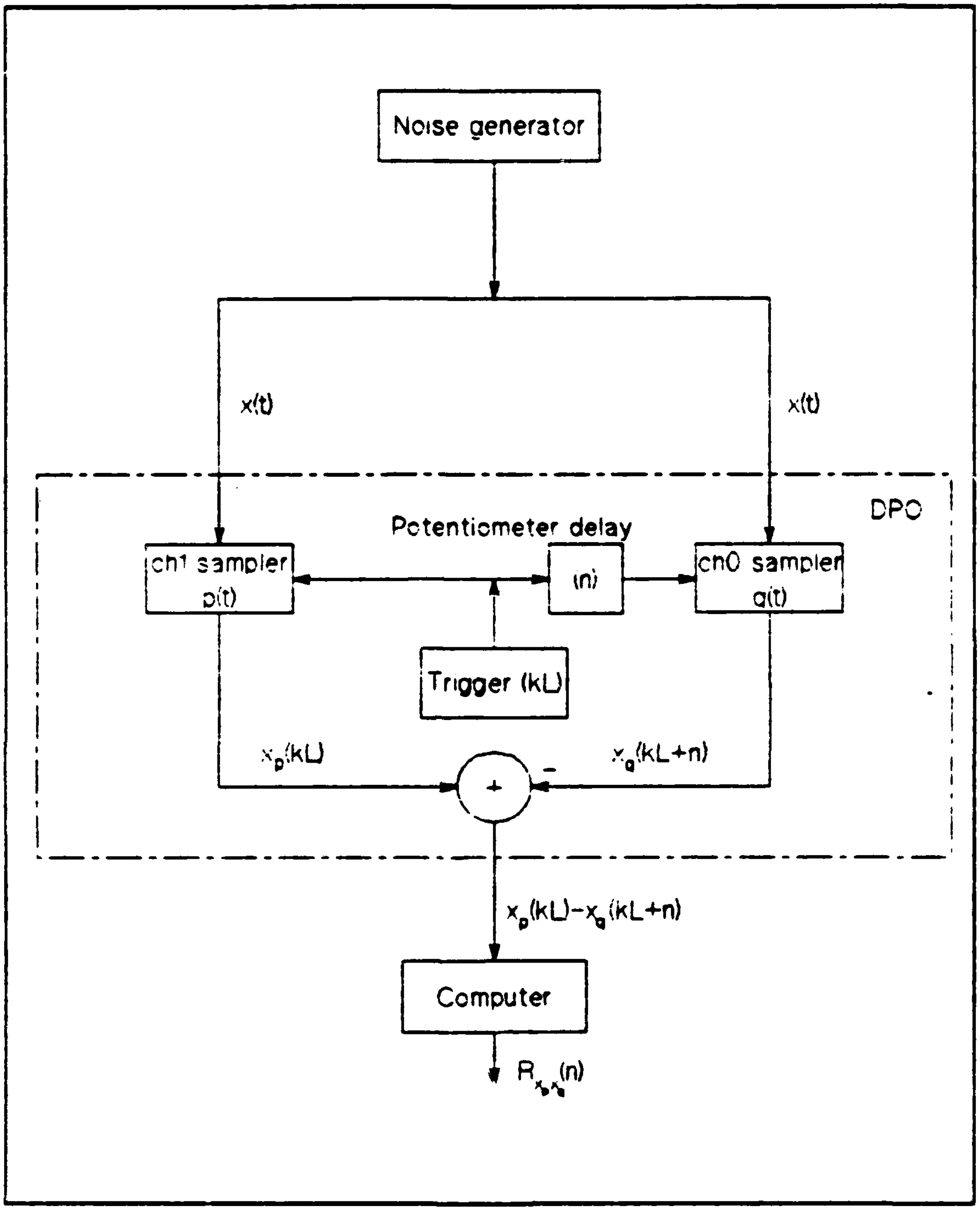


Figure 20. DPO System Crosscorrelation Measurement Setup

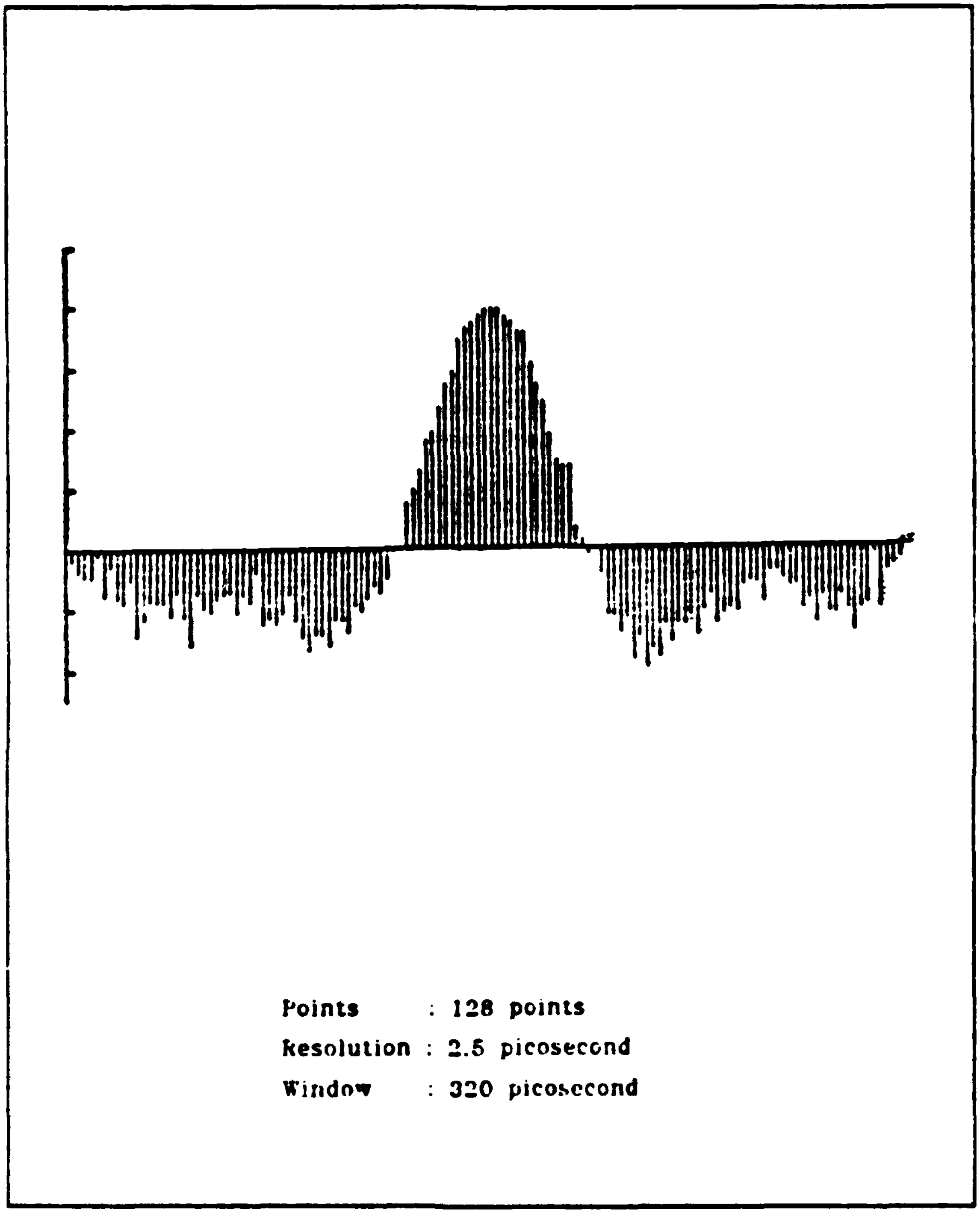


Figure 21. DPO System Crosscorrelation Function

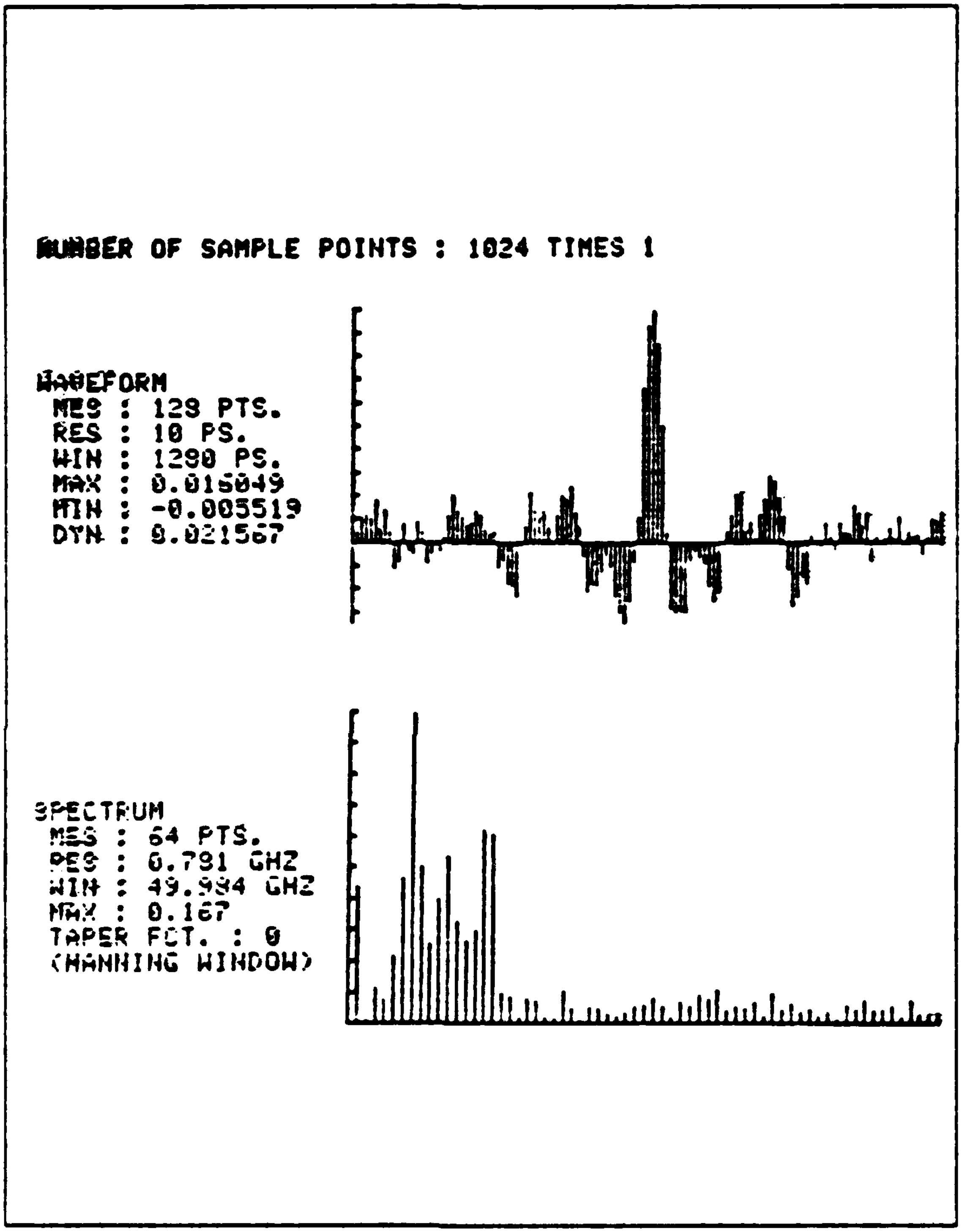


Figure 22. DPO System Crosscorrelation Function and Power Spectral Density

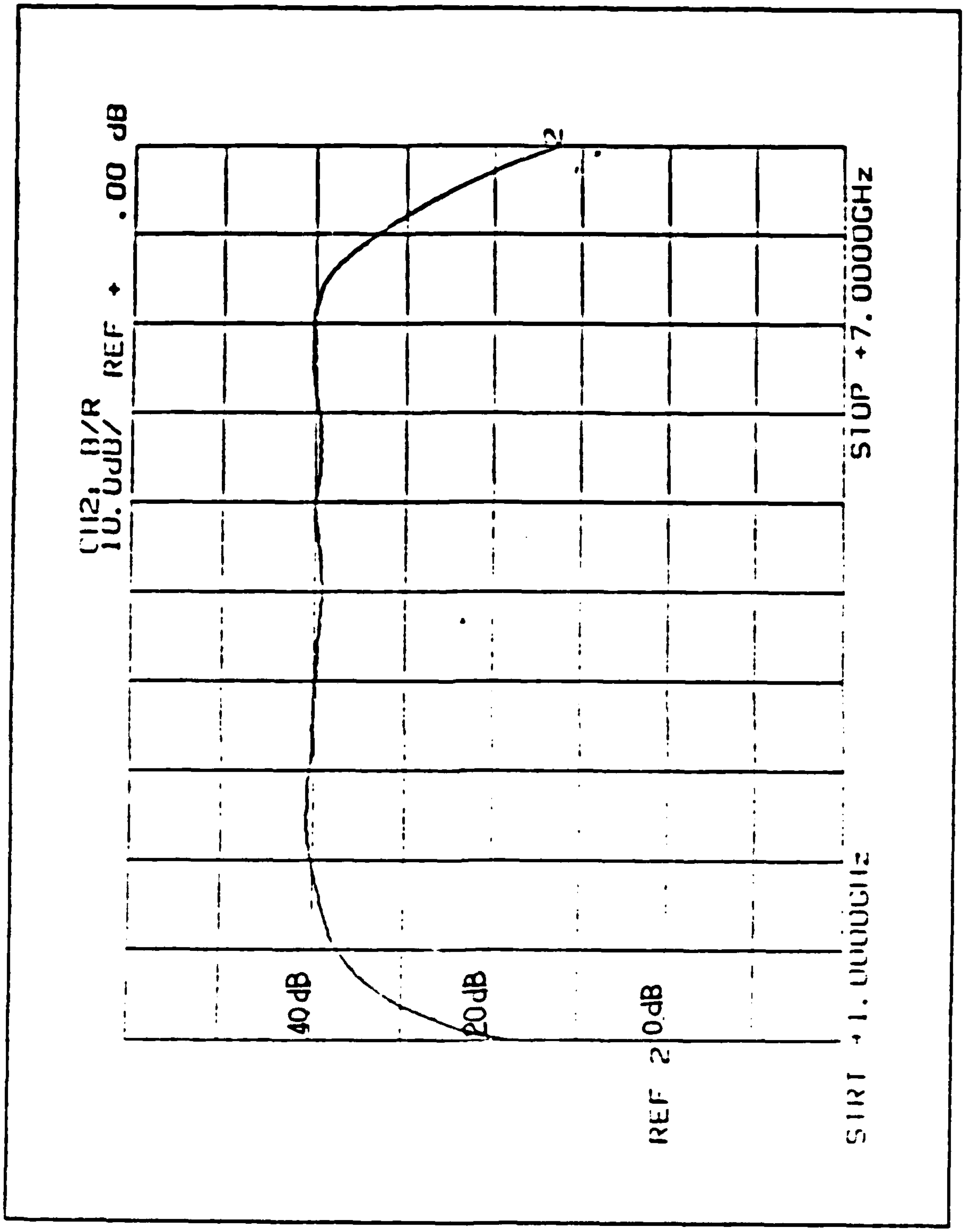


Figure 23. Frequency Response of the Avantek Amplifier

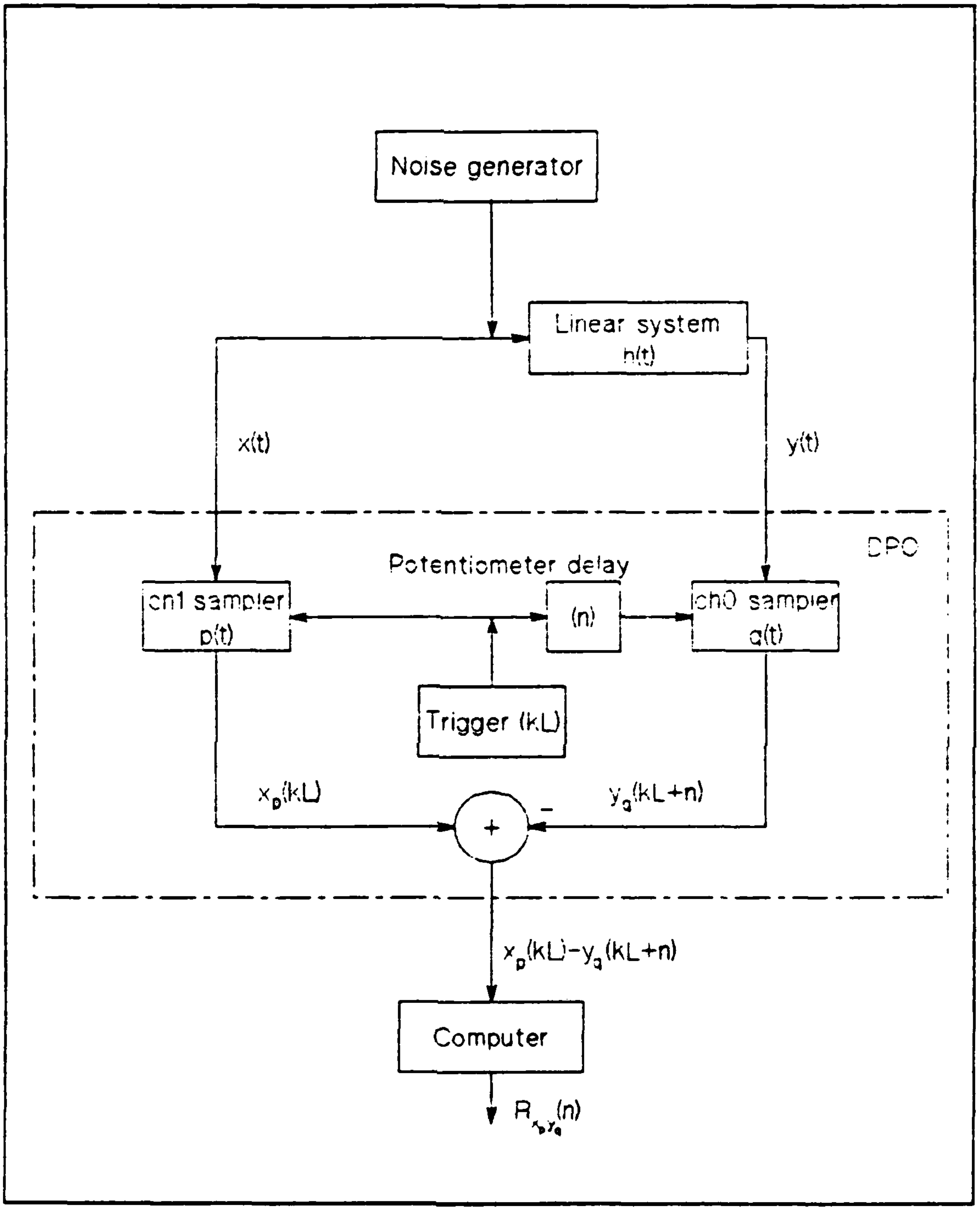


Figure 24. Noise Deconvolution Validation System Setup

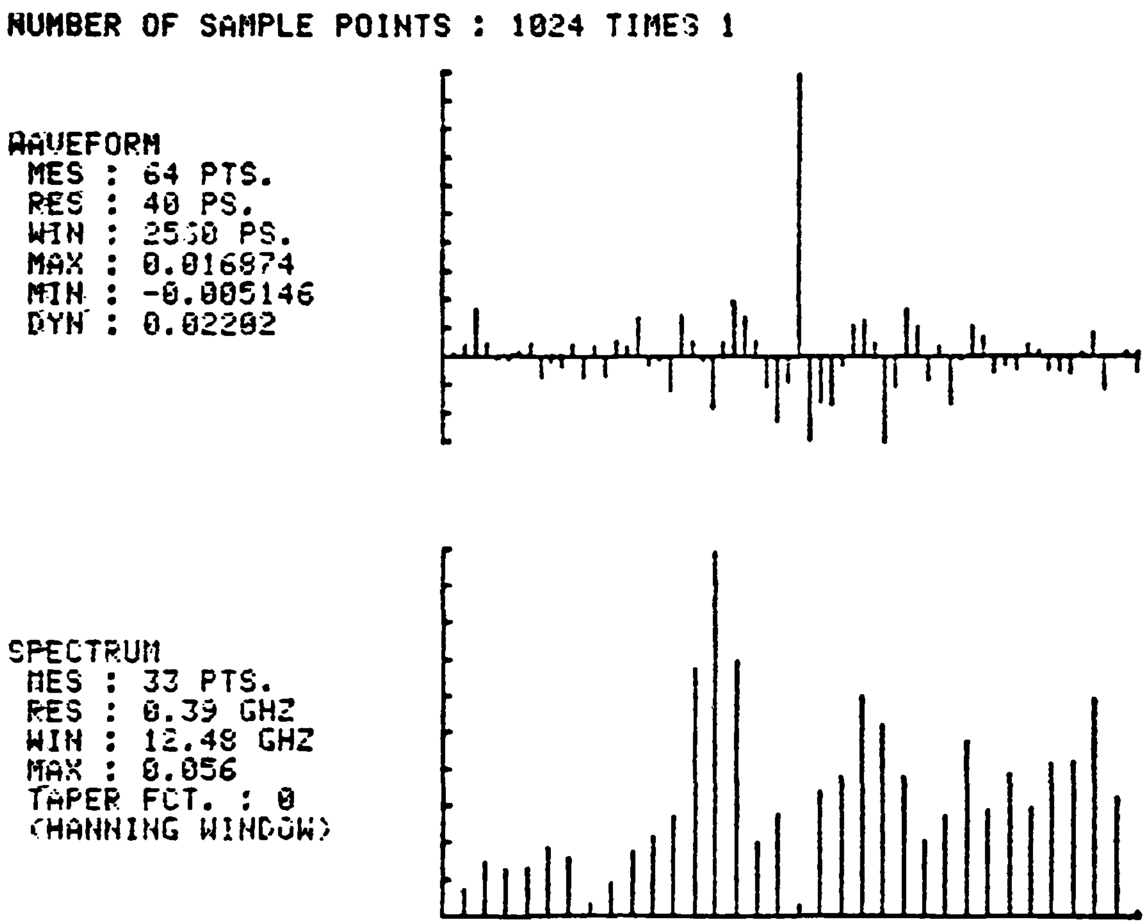


Figure 25. The System Crosscorrelation, Crosscorrelation Method

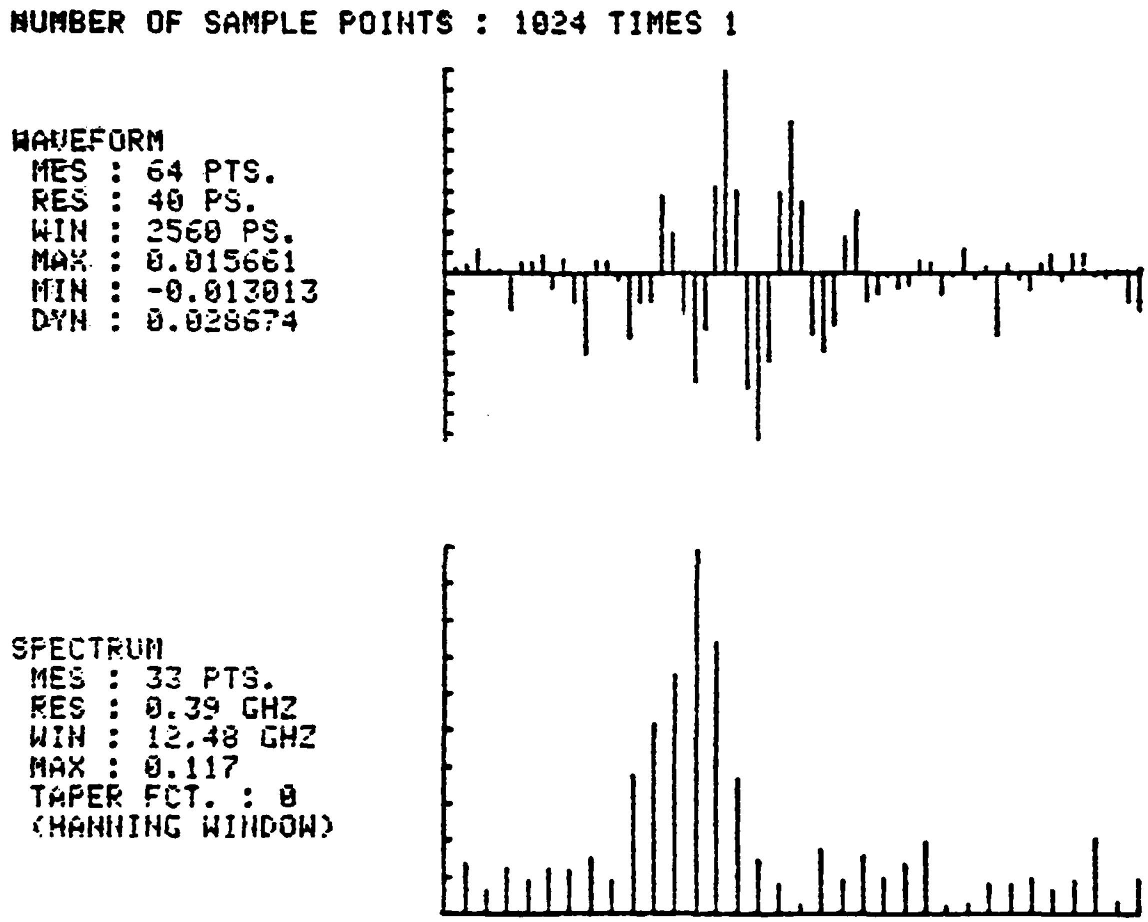


Figure 26. The Crosscorrelation of Avantek Amplifier, Crosscorrelation Method

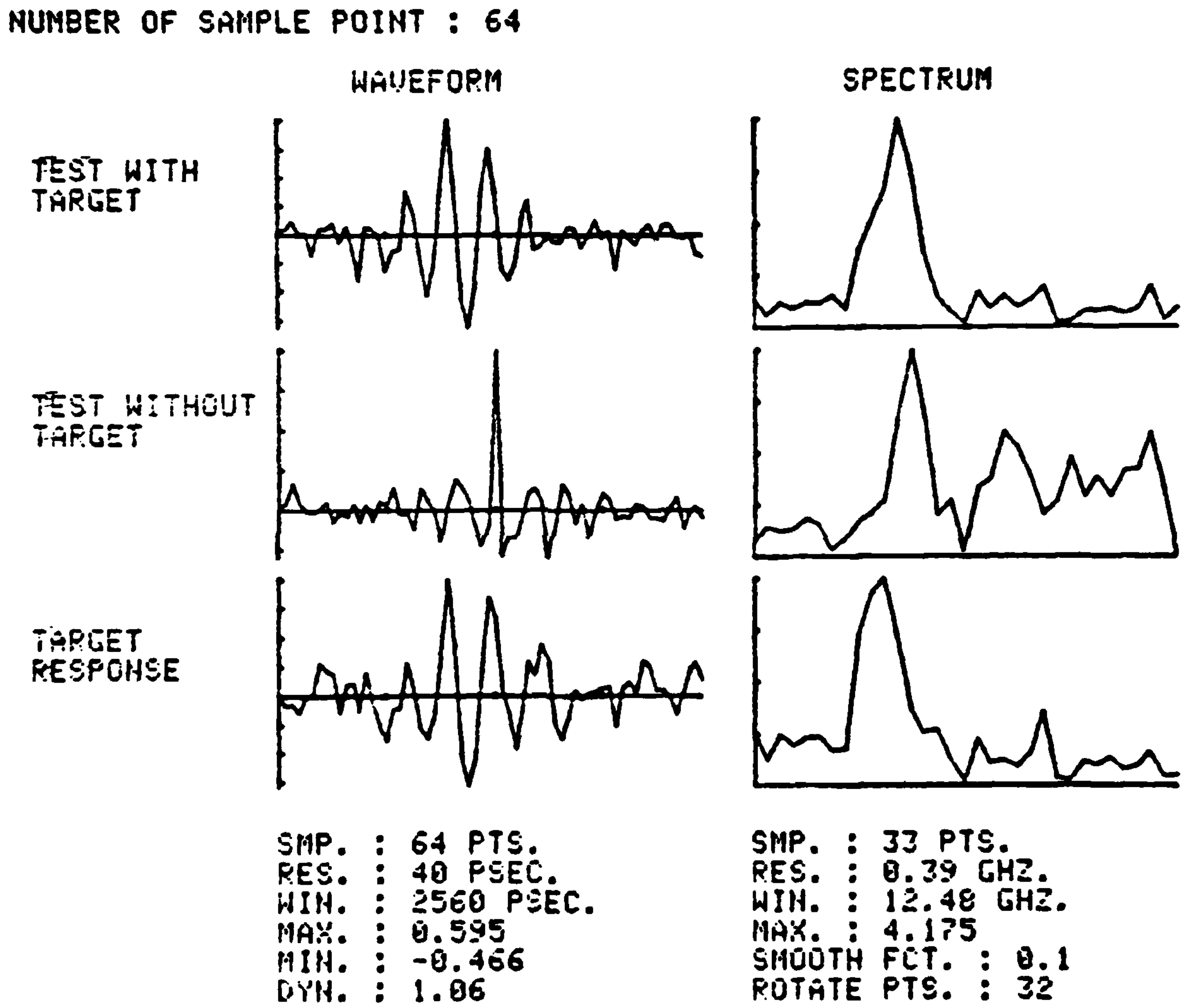


Figure 27. The System Response of Avantek Amplifier, Crosscorrelation Method

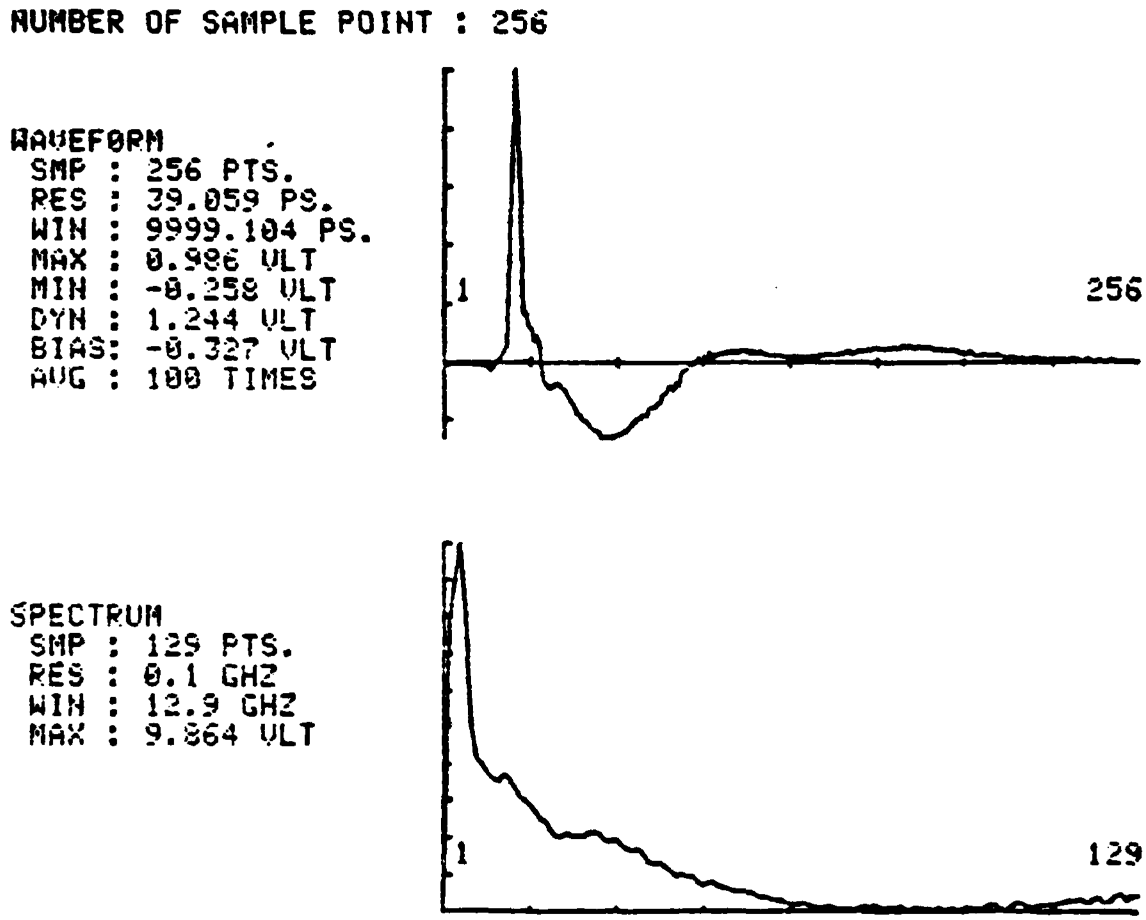


Figure 28. The Modified Pulse Input Signal, Time Domain Method

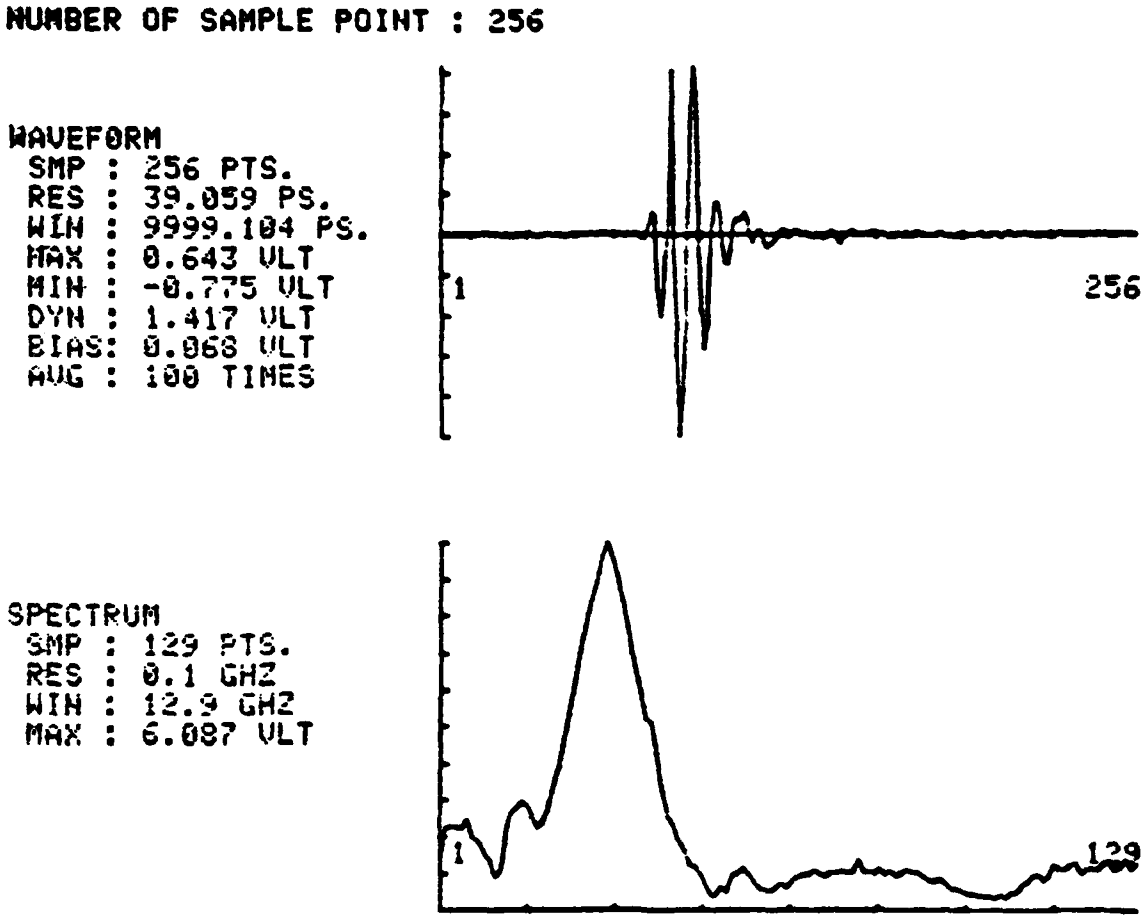


Figure 29. The Output Signal of the Avantek Amplifier, Time Domain Method

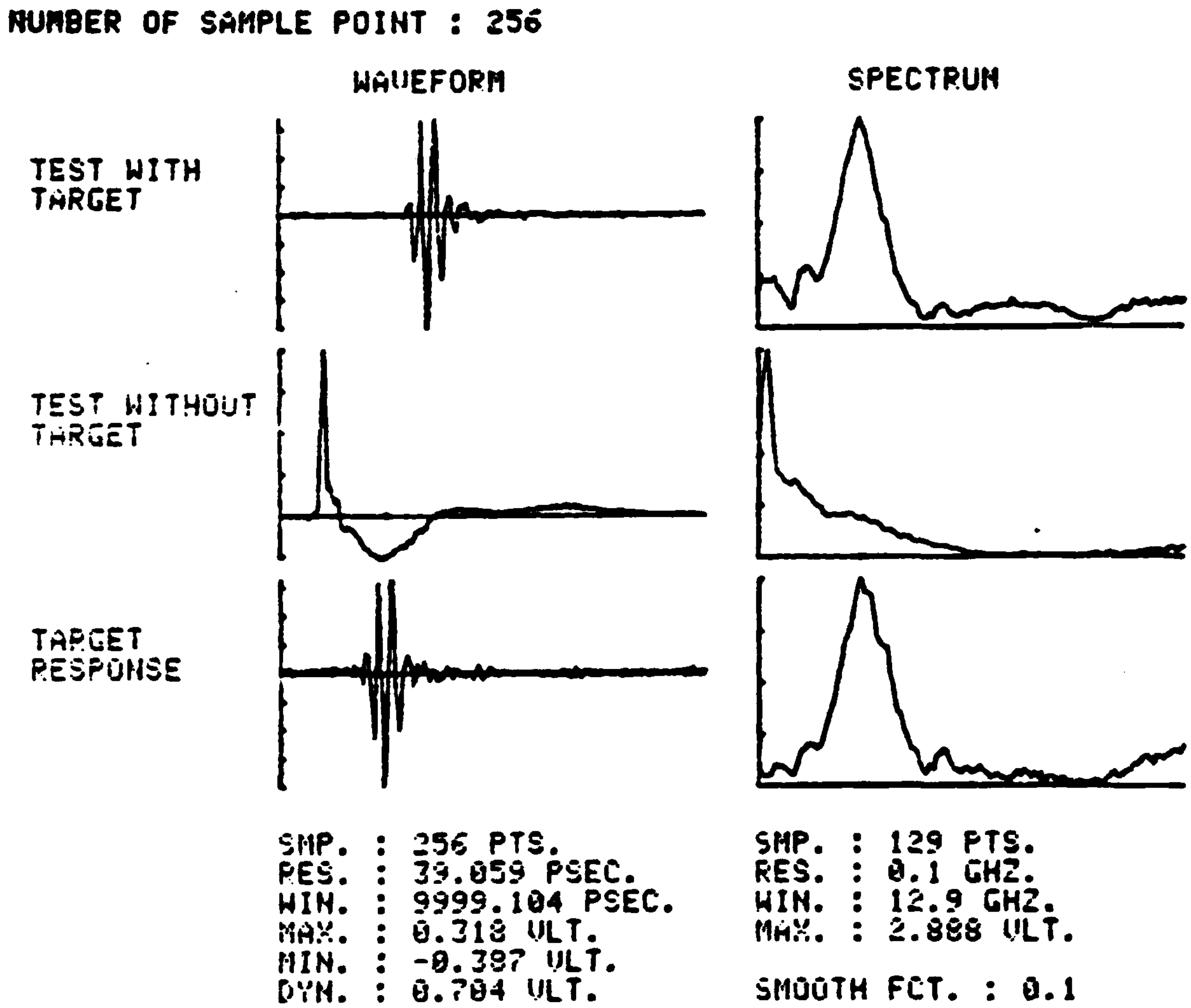


Figure 30. The System Response of Avantek Amplifier, Time Domain Method

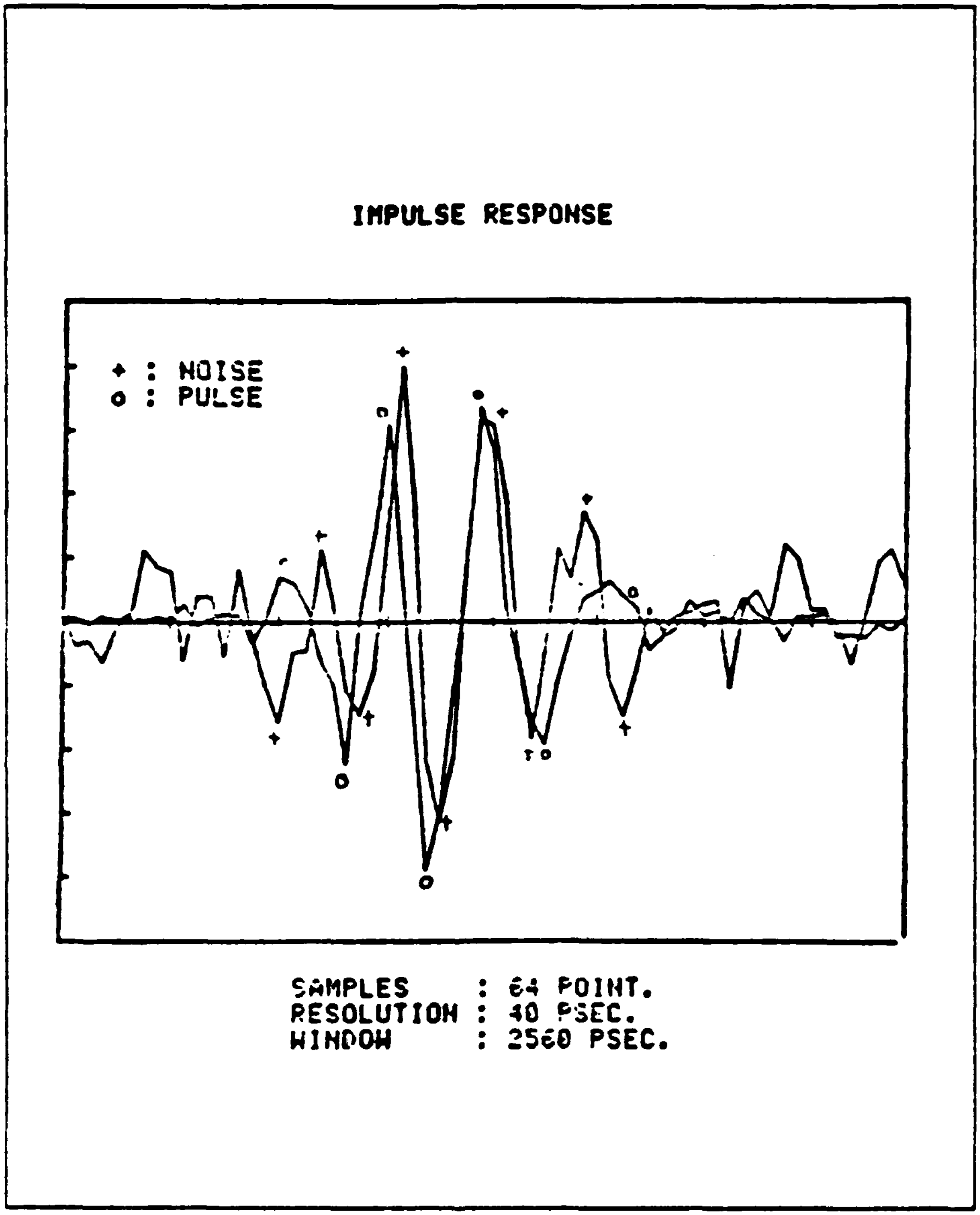


Figure 31. The Comparison of the Two Methods

V. ELECTROMAGNETIC SCATTERING MEASUREMENT

A. DESCRIPTION OF THE SCATTERING RANGE

To derive the characteristics of the noise source impulse scattering response measurement, a physical environment and equivalent model for the scattering range should be developed. Since the scattering range was already described in detail by Mariategui [Ref. 8], and McDaniel [Ref. 9], only a brief description will be given in this section.

The general physical environment of the scattering range is illustrated in Figure 1a. As shown in the illustration, the system can be divided into 5 parts.

1. Anechoic chamber
2. Transmitting and receiving antennas
3. Broadband analog noise generator
4. Dual channel sampling device (DPO)
5. Signal processor and controller (Tektronix 4052A desktop computer)

The purpose of the anechoic chamber is to shield the incident and scattered waveforms from external noise and interference effects as well as multipath contamination. The physical dimensions of the chamber are

1. Longitudinal length : 20 ft.
2. Lateral width : 10 ft.
3. Height : 10 ft.

To provide shielding from atmospheric and man-made noise, the chamber is internally covered with aluminum panels which are earth grounded. A special absorber material manufactured by Rantec, a division of Emerson Electric, is attached to the aluminum shield to absorb the electromagnetic radiation. This absorber is ridged along the length of the chamber to guide the incident wave to the back wall where the most of the incident and guided electromagnetic wave is absorbed by 18 inch pyramidal cones. Eight-inch pyramidal cones are attached to the front wall, where the antennas are mounted. These absorb back-scattered radiation and prevent reradiation of the electromagnetic wave. This material is designed to provide back-scattering attenuation of a 500 MHz signal by about 30 dB below that of a flat metal plane. Reflection coefficients are increased to about -12 dB at 1 GHz for near grazing incidence on the side-

walls, floor and ceiling. This leads to a realistic low frequency limitation of about 1 GHz due to the resultant multi-path interference.

A styrofoam column is used as the support for the various targets in the chamber. This material has a relative permittivity of about 1.1 at 3 GHz so that it gives negligible effect (reflection, refraction) to the transmitted wave but provides a stable support for the targets.

Two double-ridged horn type antennas are used for the transmitting and receiving antennas. They have a usable bandwidth of 1 to 12.4 GHz and have a relatively flat gain over the band.

The broadband analog noise generator, DPO, and the Tektronix 4052A desk top computer were already described in Chapter III.

B. DERIVATION OF NOISE SOURCE IMPULSE SCATTERRING RESPONSE MEASUREMENT FORMULA

Since the goal of this research is to validate the crosscorrelation measurement by comparing the impulse scattering response result with that from the time domain measurement, a simple sphere was chosen for the target.

An equivalent system diagram for the scattering range is shown in Figure 32. Here, the impulse responses are

1. $h_t(t)$: Target
2. $h_c(t)$: Clutter and antenna cross-coupling
3. $h_t(t)$: Transmit antenna
4. $h_r(t)$: Receiving antenna

and the signals are

1. $x(t)$: Transmitted (source) signal produced by DPO
2. $y(t)$: Received (back scattered) signal
3. $x_z(kL)$: Sampled transmitted sequence
4. $y_q(kL + n)$: Sampled received sequence
5. $z(n)$: Stored sequence ($X - Y$)
6. $R_{x_z y_q}(n)$: Crosscorrelation output

Compared with the discussion in Section IV.C, the system impulse response in the anechoic chamber is more complicated than a simple 2-port network response. The impulse response of the anechoic chamber is

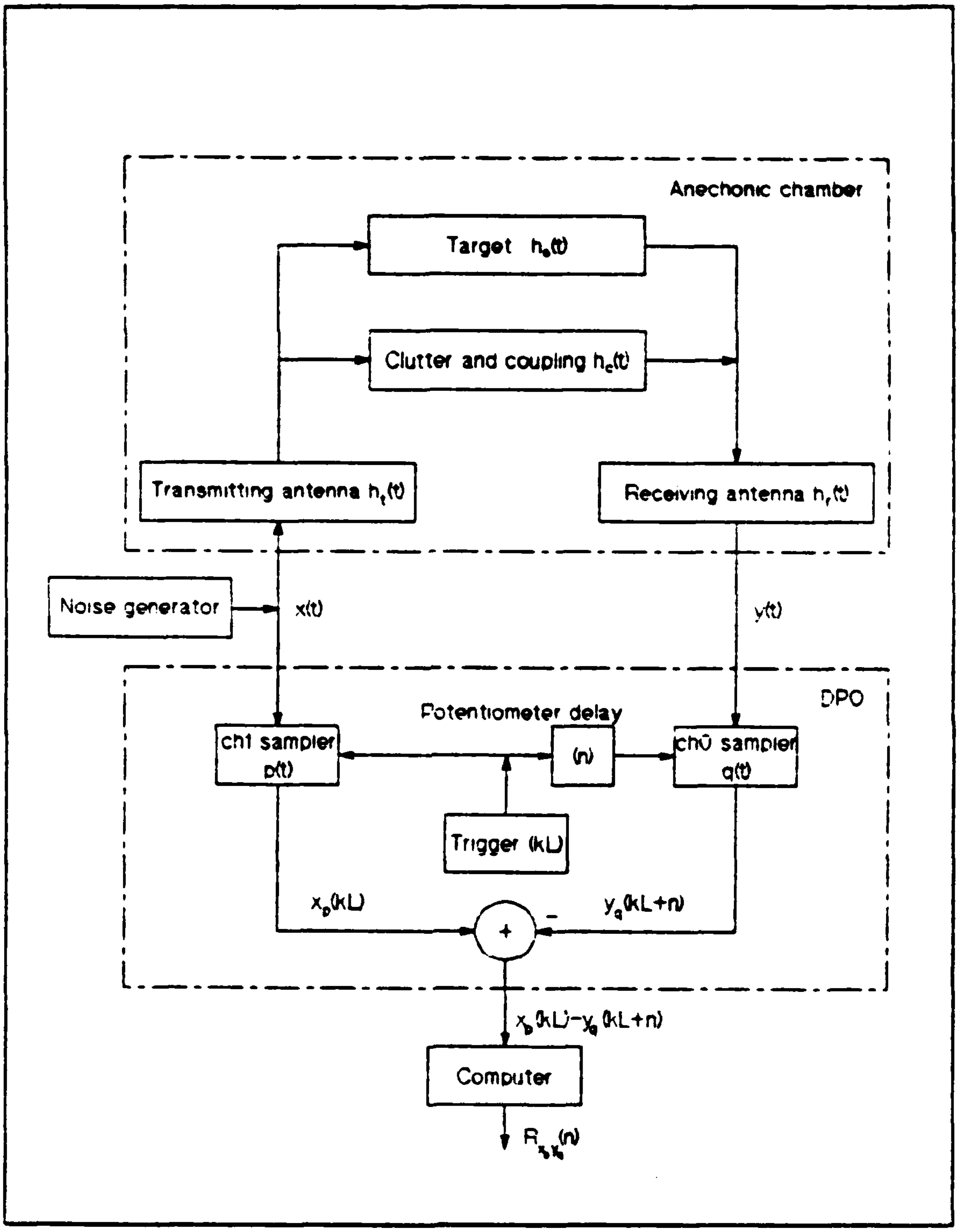


Figure 32. A System Diagram of the Scattering Range

$$
\begin{aligned}
h(t) &= h_t(t) * (h_s(t) + h_c(t)) * h_r(t) \\
&= (h_t(t) * h_r(t)) * (h_s(t) + h_c(t)) \\
&= h_a(t) * (h_s(t) + h_c(t))
\end{aligned}
\tag{5.1}
$$

This equation suggests the need of at least three sets of measurements for extracting the target response $h_s(t)$. Using our method, the three crosscorrelations that must be measured are

$$
\begin{aligned}
R_{x_p y_q}(n)_1 &= R_{pq}(t) * R_{xy}(t) \\
&= [\, R_{pq}(t) * R_x(t) * h_t(t) * h_r(t) \,] * h_c(t) \\
&= \phi(t) * h_c(t)
\end{aligned}
\tag{5.2}
$$

$$
R_{x_p y_q}(n)_2 = \phi(t) * [\, h_p(t) + h_c(t) \,] \tag{5.3}
$$

$$
R_{x_p y_q}(n)_3 = \phi(t) * [\, h_s(t) + h_c(t) \,] \tag{5.4}
$$

where,

$$
\phi(t) \equiv \hat{R}_{pq}(t) * R_x(t) * h_t(t) * h_r(t) \tag{5.5}
$$

However, experiments revealed the need of one more background measurement for better subtraction of the background noise. This is because of the use of a relatively short time window compared with the difference of the propagation delays of different targets, (the calibration target, and real target). Therefore, instead of Equation (5.2) to (5.4), we use Equation (5.6) to (5.9).

$$
\hat{R}_{x_p y_q}(n)_{12} = \hat{\phi}(n) * \hat{h}_c(n)_2 \tag{5.6}
$$

$$
\hat{R}_{x_p y_q}(n)_{13} = \hat{\phi}(n) * \hat{h}_c(n)_3 \tag{5.7}
$$

$$
\hat{R}_{x_p y_q}(n)_2 = \hat{\phi}(n) * [\, \hat{h}_p(n) + \hat{h}_c(n)_2 \,] \tag{5.8}
$$

$$
\hat{R}_{x_p y_q}(n)_3 = \hat{\phi}(n) * [\, \hat{h}_s(n) + \hat{h}_c(n)_3 \,] \tag{5.9}
$$

where

$$\hat{\phi}(n) \equiv \hat{R}_{pq}(n) * \hat{R}_x(n) * \hat{h}_t(n) * \hat{h}_r(n) \tag{5.10}$$

$$\hat{h}_c(n)_3 \simeq \hat{h}_c(n-m)_2 \tag{5.11}$$

Here, m is the time delay due to the different measurement time origin caused by the physical shape of each target. So, the best delay could be determined by the difference of the transit time of the leading edge of the scattered electromagnetic wave for each target.

$$m = \text{Integer}\left\{ \frac{2D}{cT_s} \right\}$$

In this equation, D denotes the radial difference of the two spheres and c represents the free space velocity of an electromagnetic wave. This is illustrated in Figure 33 and an example of this effect is shown in Figure 34 using an 1 sq. ft. copper sheet target for better reflection.

The next thing to do after the four measurements of the crosscorrelation is the extraction of the target response $h_t(n)$. This is performed in two steps.

1. Clutter subtraction.
2. Crosscorrelation deconvolution using Riad's method.

At first, subtraction of the clutter effect was performed. Let the subtracted result be denoted as

$$\begin{aligned}\hat{R}_{21}(n) &\equiv \hat{R}_{x_p y_q}(n)_2 - \hat{R}_{x_p y_q}(n)_{12} \\ &= \hat{\phi}(n) * \hat{h}_p(n)\end{aligned} \tag{5.12}$$

$$\begin{aligned}\hat{R}_{31}(n) &\equiv \hat{R}_{x_p y_q}(n)_3 - \hat{R}_{x_p y_q}(n)_{13} \\ &= \hat{\phi}(n) * \hat{h}_s(n)\end{aligned} \tag{5.13}$$

The following is the deconvolution for extracting the response of the target. The key point of the deconvolution is the use of the calibration target which has a known computed transfer function. The Mie-series program prepared by Professor Morgan computes the transfer function of the sphere [Ref. 9].

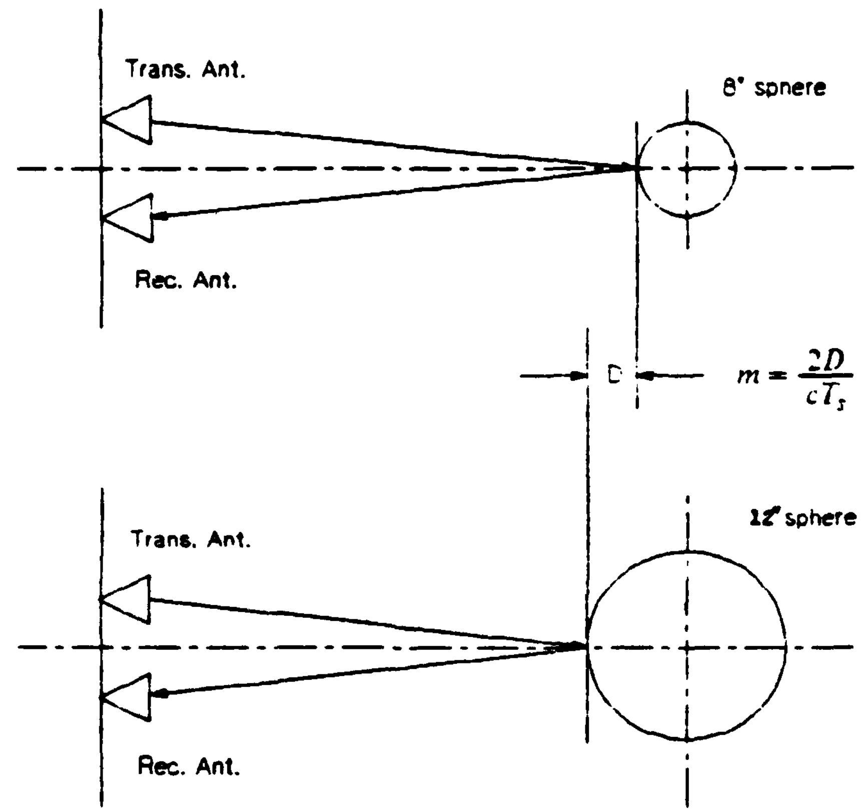
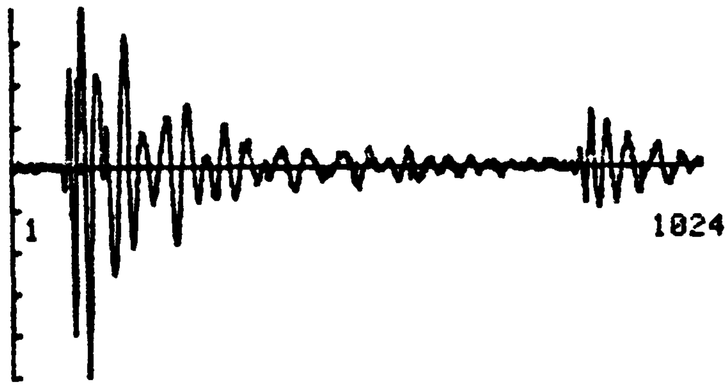


Figure 33. Path Differences for Target and Calibration Spheres

NUMBER OF SAMPLE POINT : 1024

WAVEFORM
SMP : 1024 PTS.
RES : 19.529 PS.
WIN : 19997.696 PS.
MAX : 0.055 ULT
MIN : -0.073 ULT
DYN : 0.128 ULT
BIAS: 0 ULT
AVG : 100 TIMES



NUMBER OF SAMPLE POINT : 1024

WAVEFORM
SMP : 1024 PTS.
RES : 19.529 PS.
WIN : 19997.696 PS.
MAX : 0.054 ULT
MIN : -0.074 ULT
DYN : 0.127 ULT
BIAS: 0 ULT
AVG : 100 TIMES

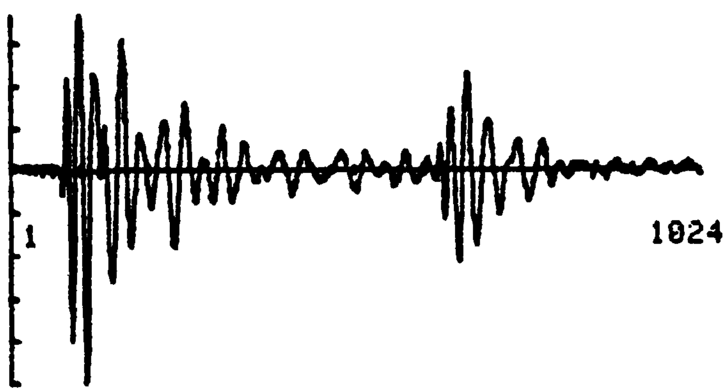


Figure 34. Examples of the Delayed Signal Due to Different Paths

Let $H_{pc}(f)$ represent the computed transfer function of the 8 inch sphere. For an ideal case, the transfer function of the target could be computed as

$$H_s(f) = \frac{S_{31}(f)}{S_{21}(f)} \; H_{pc}(f) \tag{5.14}$$

where $S_{31}(f)$ and $S_{21}(f)$ are the Fourier transforms of the crosscorrelations $R_{31}(t)$ and $R_{21}(t)$. Since we are dealing with the estimated crosscorrelations, Riad's method, as described in Section II.D, is applied.

$$\hat{H}_s(k) = \frac{\hat{S}_{31}(k)\,\hat{S}_{21}^{*}(k)}{|\hat{S}_{21}(k)|^2 + \lambda W_{21}} \; H_{pc}(k) \tag{5.15}$$

where,

$$W_{21} = \frac{1}{K} \sum_{k=0}^{K-1} \hat{S}_{21}^{2}(k) \tag{5.16}$$

Finally, the smoothed estimation of the impulse response will be obtained from the inverse Fourier transform of Equation (5.15).

C. ELECTROMAGNETIC SCATTERING CROSSCORRELATION MEASUREMENT

First, a 12 inch calibration target measurement of $\hat{R}_{x_p y_q}(n)_2$ was performed. To estimate a suitable time window, a pulse signal was first used as the excitation in the anechoic chamber. The measured backscattered signal contains several constituents: direct antenna coupling; chamber clutter and target scattering which is modified by the antenna responses and multipath. The target pedestal is located approximately 8 feet from the horn antennas.

An additional 7 feet of cable delay line was linked between the transmitter power splitter and the channel 0 sampler to show the two signals in the same time window. At first, a directional coupler was selected instead of the power splitter since the directional coupler transmits most of the input signal. However, it was found that the directional coupler provided a significant attenuation in its high frequency band. The result of the alignment test is illustrated in Figure 35. The leading edges of the two signals are aligned

when the potentiometer reading indicates 195. The time width of the sphere response was about 2 nanoseconds.

Next, the noise source was applied to measure the electromagnatic scattering cross-correlation measurement. Since the pulse response is limited to about 7 GHz [Fig. 23.], a set of 64 samples with a sampling interval of 40 picoseconds was chosen to cover a 2 nanosecond time interval. This produces a Nyquist frequency of 12.7 GHz.

Unfortunately, the measured value of the crosscorrelation was significantly corrupted by the noise and system errors so that it was impossible to use. Since then, the effort was focused on finding the source of the errors and on the ways to avoid it. However, the answer is that, at this time, we could not reduce the error sufficiently to makes the estimation useful. In fact, the fight against the error noise for the signal noise source spans the whole history of this research. The situation in the scattering measurement offers signifcantly less output signal strength than was observed in the initial tests using lumped filters. This degradation of signal appears to have exceeded the limits of fidelity needed to demonstrate any viability of the measurement. In short, the results appeared as "garbage" that could not be reproduced on any two measurements. The signal was essentially buried in the noise.

In addition to the description about the noise in Chapter II, the sampled sequence of the two channels are modeled as

$$X_p(n) = X(n) * p(n) + j_x(n) + Q_x(n) + d_x(n) + N_x(n) + D_x(n) \tag{5.17}$$

$$Y_p(n) = Y(n) * q(n) + j_y(n) + Q_y(n) + d_y(n) + s_y(n) + u_y(n) + N_y(n) + D_y(n) \tag{5.18}$$

where,

1. $X(n)$: Input signal
2. $p(n)$: Impulse response of the input channel sampler
3. $j_x(n)$: Jitter noise of the input channel
4. $Q_x(n)$: Quantization noise of the input channel
5. $d_x(n)$: Drift (nonstationary) noise of the input channel
6. $N_x(n)$: Other noise (Thermal noise etc.)
7. $D_x(n)$: DC bias due to the DPO vertical alignment
8. $Y(n)$: Output signal
9. $q(n)$: Impulse response of the output channel sampler
10. $j_y(n)$: Jitter noise of the output channel

11. $Q_y(n)$: Quantization noise of the output channel
12. $d_y(n)$: Drift (nontationary) noise of the output channel
13. $s_y(n)$: Sampling interval scaling noise of the output channel
14. $u_y(n)$: Mispositioning noise
15. $N_y(n)$: Other noise (Thermal noise etc.)
16. $D_y(n)$: DC bias due to the DPO vertical alignment

It may be surmised that the poor performance is probably caused from the nonstationary characteristics of the DPO, as summarized in Section III.C. This includes the jitter noise and quantization noise. The estimation error for a stationary process should be reduced by increasing the number of sample points. As shown in Figure 36, the error noise is not linearly reduced by increasing the number of the samples. This reveals the existence of other sources of the error such as nonstationary noise (caused by the drift problem) which may give a sudden level of noise that can not be reduced by the operator.

Figure 36 reveals that the electromagnetic scattering crosscorrelation measurement for the 12 inch sphere is significantly corrupted by the error noise although the result came from the computation of 8192 samples. Therefore, it might be almost impossible to perform deconvolution under such a low SNR environment unless other ways can be found to increase the SNR of the estimated value. One such way, which may solve this problem, is the use of a new generation of sampling devices, such as the Hewlett Packerd Model 54120 digitizing oscilloscope. This DPO has a sampling rate up to 20 GHz and offers computer controlled time-offsets of its 4 channels. A follow-on investigation will consider the application of the HP-DPO to this research.

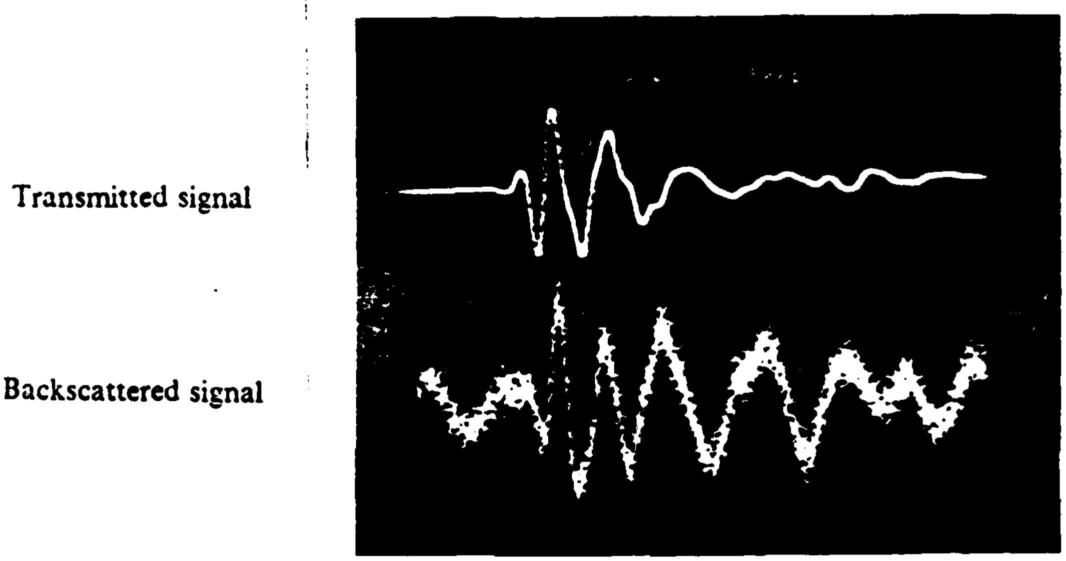


Figure 35. Time Origin Alignement Test of the 8 Inch Sphere

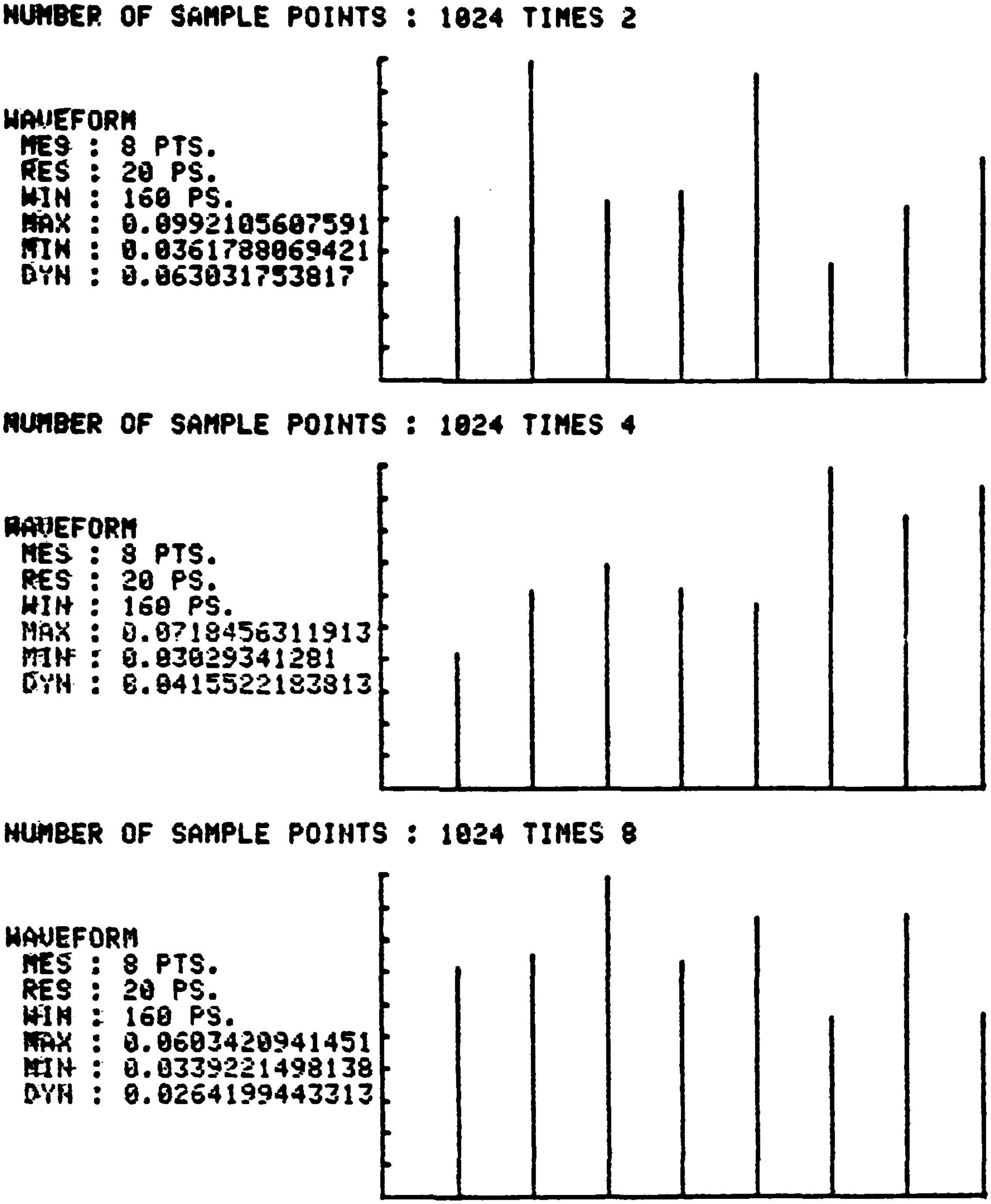


Figure 36. The Fluctuation of the Estimated Crosscorrelation Due to the Error Noise

VI. CONCLUSIONS

A. SUMMARY

The main effort described in this thesis is to demonstrate the viability of impulse response measurements using a broadband random noise source. An application of this system is radar target detection and tracking, where it would offer the following potential advantages:

1. Low cost noise sources are available.
2. Deception in radar applications, (jammer or natural noise appearance).

The first step of the research was to develop the theory of noise source impulse response measurements. An analog version of the crosscorrelation was derived followed by development of the three crosscorrelation measurement methods. The third measurement method (pre-subtracted single channel measurement with arbitrary sampling rate) was selected after much effort in trying to use method 2. The bias and variance test of the estimated crosscorrelation followed. It was shown that the estimation is unbiased, and consistent. Finally, the effect of the sampler on the signal as well as the application of an optimal deconvolution technique were considered.

The next step was devoted to the experimental configuration. The characteristics of the Tektronix DPO and noise generator were investigated. It seems that the Tektronix DPO is not the ideal device for this research since it exhibits many problems for these measurements. Some of these are the drift problem, the relatively large amount of jitter noise (about 1/5 of the signal strength), a sampling interval scaling problem, etc. An effort to minimize this error noise was attempted. Detailed tests were performed, and it was revealed that the system crosscorrelation included errors in its peak-to-peak value of about 1/20 of its maximum signal power.

The calibration and validation test were then performed. An Avantek solid-state microwave amplifier was selected as the test item. The crosscorrelation measurements of the sampling system and the Avantek amplifier were performed. A smoothed frequency response of the Avantek amplifier was computed using the Riad's method. Then, the impulse response of the Avantek amplifier was obtained using the inverse Fourier transform. This was compared to results obtained via a direct pulse excitation measurement.

Finally, an electromagnetic scattering measurement was attemped after considering the requisite mathematical foundation. Four measurements were needed in practice although the theory requires three measurements. The scattering measurement provided insufficient fidelity due to hardware limitations of the Tektronix DPO. Major sources of error in the current system include nonstationary drift, jitter,and mispositioning.

B. FUTURE CONSIDERATIONS

The main difficulties encountered in this research resulted from the use of a less than ideal sampling device that could not sample sufficiently fast to satisfy the Nyquist criterion. Further, it has been revealed that this sampling device has many problems as described in the previous section.

The significant payoff of this research mandates that it be continued with vigorous attempts to alleviate the hardware deficiencies encountered in this initial effort. The use of a new generation digital processing oscilloscope by Hewlett Packard is a step in the right direction since this device allows computer control of the temporal offset of each channel with an accurate resolution of 10 picoseconds. The essentially drift-free performance, coupled with automated time-offsets in the crosscorrelation data acquisition, will allow large ensemble averages to be employed with much shorter measurement times than have been the case here.

APPENDIX COMPUTER PROGRAM LISTINGS

```
100 REM ***** PROGRAM FILE NO.1 ****************************************
104 REM ***** CROSSCORRELATION MEASUREMENT USING PRE-SUBTRACTION METHOD
105 REM ***** EACH MEASUREMENT MUST BE DONE IN THE PREDETERMINED PERIOD
106 REM ***** DPO VERTICAL MODE : ADD
107 REM ***** DPO CHANNEL 0     : INVERT MODE
108 REM
109 PAGE
110 PRINT "NOISE SOURCE CROSSCORRELATION MEASUREMENT PROGRAM"
120 PRINT "JJ"
130 PRINT "IS THIS THE INITIAL RUN? (Y/N)"
140 INPUT Y$
150 IF Y$="N" THEN 430
170 REM
180 REMLIS
190 REM
200 REM
205 Cr=0
210 PRINT "TEST (WAVEFORM) ID?"
220 INPUT W$
270 PRINT "TAPE FILE NUMBER?"
280 INPUT Ta
290 PRINT "NUMBER OF MEASUREMENT? ( POWER OF 2 ===> 16, 32, 64, 128 ) "
292 INPUT M
300 PRINT "NUMBER OF TIME POINTS? (CHOOSE ONE)"
302 PRINT "  <1>:256   <2>:512   <3>:1024 "
304 INPUT R
310 PRINT "NUMBER OF SAMPLE SETS?"
315 INPUT Av
340 PRINT "HOR. SCALE (TIME) IN PICOSEC.?"
350 INPUT H
360 PRINT "VER. SCALE (VOLTAGE) IN MILLIVOLT?"
362 INPUT V
370 REM
374 Tp=0
```

```
380 M1=0
382 IF Cr=2 THEN 390
384 DELETE Ww,Wf,Vr0,Vr1
386 DIM Ww(M),Wf(M),Vr0(M),Vr1(M)
390 GO TO 530
400 REM
410 REM
420 REM
430 PRINT "INSERT THE DATA TAPE IN THE TAPE DRIVE AND TYPE <GO>."
440 INPUT G$
450 PRINT "TAPE FILE NUMBER?"
460 INPUT Ta
470 FIND @33:Ta
480 READ @33:W$,D$,Ta,D,R,Av,M,M,H,V,Tp,D
485 DELETE Ww,Wf,Vr0,Vr1
486 DIM Ww(M),Wf(M),Vr0(M),Vr1(M)
487 READ @33:Ww,Wf,Vr0,Vr1
490 REM
500 REM
510 REM
520 REM
525 REM
530 N1=128*2↑R
535 Nt=N1*Av
540 GOSUB 1430
550 PRINT "DO YOU NEED ANY CORRECTION? "
552 PRINT " <1>:YES     <2>:YES, EXCEPT THE DATA MEASURED"
554 PRINT " <3>:NO      <4>:NO, WANT SIGNAL ANALYSIS"
560 INPUT Cr
570 GO TO Cr OF 210,210,580,1150
580 PRINT "WELL, NOW THE ITIALIZATION IS DONE."
590 PRINT "TYPE <GO> FOR THE NEXT STEP. (MEASUREMENT)"
600 INPUT G$
610 PRINT "GGGGGGGGGGGG"
620 REM
```

```
630 REM
640 REM
650 REM
670 PAGE
680 PRINT "PERFORMING THE MEASUREMENT"
700 INPUT G$
710 Dcc=0
713 M1=M
715 Ww=0
717 PRINT "PLEASE WAIT FEW SECONDS FOR FIRST MEASUREMENT"
720 FOR I=1 TO M
730    GOSUB 1620
750    GOSUB 1900
800 NEXT I
810 PRINT "GGG"
820 PAGE
830 PRINT "NEXT, YOU NEED DC COMPONENT MEASUREMENT."
840 INPUT G$
845 Dcc=1
850 DELETE Dc
860 DIM Dc(4)
863 M1=4
865 Dc=0
870 FOR I=1 TO 4
880    GOSUB 1620
900 NEXT I
910 Ww=SUM(Dc)/4-Ww
915 Ww=Ww/2
920 REM
930 REM
935 PRINT "GGGGGGG"
937 PAGE
940 PRINT "NOW, YOU ARE OUT OF MEASUREMENT STEP."
950 PRINT "TYPE <GO> FOR THE NEXT STEP. (PLOT AND SAVE)"
960 INPUT G$
```

```
1000 REM
1110 REM
1120 REM
1130 REM
1140 REM
1150 GOSUB 2100
1151 PRINT "                    FREQUENCY CHARACTERISTIC COMPUTATION "
1152 GOSUB 3000
1160 PRINT "DO YOU WANT SAVE? (Y/N)"
1170 INPUT Ss$
1180 IF Ss$="N" THEN 1280
1190 PRINT "INSERT THE DATA TAPE IN THE TAPE DRIVE AND TYPE <GO>."
1200 INPUT G$
1204 PRINT "TAPE FILE NUMBER?"
1206 INPUT Ta
1210 FIND @33:Ta
1212 D$="DUMMY"
1214 D=0
1216 Vr0=0
1218 Vr1=0
1220 WRITE @33:W$,D$,Ta,D,R,Av,M,M,H,V,Tp,D,Ww,Wf,Vr0,Vr1
1230 REM
1240 REM
1250 REM
1260 REM
1280 PRINT "NOW, YOU ARE READY TO QUIT THE TEST"
1290 PRINT "DO YOU WANT TO TEST AGAIN? (Y/N)"
1300 INPUT Tt$
1310 IF Tt$="Y" THEN 520
1320 PRINT "THANK YOU FOR USING THIS PROGRAM."
1325 PRINT "PLEASE MAKE ANOTHER MEASUREMENT SOON."
1330 REM
1340 REM
1350 REM
1360 REM
```

```
1370 REM
1380 END
1390 REM************************************
1400 REM
1410 REM
1420 REM
1430 REM *** CURRENT STATUS DISPLAY SUBR. ***
1440 PAGE
1445 PRINT "    *** CURRENT TEST STATUS ***"
1450 PRINT "JJ";
1460 PRINT "    TEST ( WAVE FORM ) ID    : ",W$
1490 PRINT "    TAPE FILE NUMBER         : ",Ta
1500 PRINT "J"
1510 PRINT "    NUMBER OF MEASUREMENT    : ",M
1515 PRINT "    NUMBER OF SAMPLE POINT   : ",N1;" TIMES ";Av
1520 PRINT "J"
1530 PRINT "    HOR. SCALE IN PICO SEC.  : ",H
1540 PRINT "    VER. SCALE IN MILI VOLT  : ",V
1550 PRINT "JJ"
1560 RETURN
1570 REM
1580 REM
1590 REM
1600 REM
1610 REM
1620 REM *** SCATTERING MEASUREMENT SUBROUTINE ***
1685 GO TO R OF 1688,1690,1692
1688 PRINT @10:"2 5 6 >P/W"
1689 GO TO 1700
1690 PRINT @10:"5 1 2 >P/W"
1691 GO TO 1700
1692 PRINT @10:"1 0 2 4 >P/W"
1693 REM
1694 REM
1695 REM
```

```
1700 DELETE W0,Wr
1701 DIM W0(N1),Wr(N1)
1702 Men0=0
1704 W0=0
1706 Wr=0
1712 FOR J=1 TO Av
1714     ON SRQ THEN 1820
1716     S=0
1718     PRINT @10:"AQR"
1720     IF S<>66 THEN 1720
1722     IF J<>Av THEN 1730
1724     PRINT "GG"
1725     REM
1730     PRINT @10:"0 WFM SENDX"
1740     IF S<>210 THEN 1740
1750     INPUT @10:N1,Z1,X,Z2,Y
1760     INPUT @10:W0
1818     GO TO 1830
1820     POLL D,S;10
1822     RETURN
1824     REM
1826     REM
1828     REM
1830     Wr=W0*W0
1840     IF Dcc=1 THEN 1870
1850     Nw(I)=Nw(I)+SUM(Wr)/Nt
1860     GO TO 1880
1870     Dc(I)=Dc(I)+SUM(Wr)/Nt
1880 NEXT J
1890 RETURN
1891 REM
1892 REM
1893 REM
1894 REM
1895 REM
```

```
1900 REM *** CURRENT MEASUREMENT PLOT SUBR. ***
1902 PAGE
1905 DELETE P
1910 DIM P(5)
1915 P=0
1920 GO TO I OF 1970,1960,1950,1940.1930
1930 P(1)=Ww(I-4)
1940 P(2)=Ww(I-3)
1950 P(3)=Ww(I-2)
1960 P(4)=Ww(I-1)
1970 P(5)=Ww(I)
1980 CALL "MAX",P,Mx,J
1990 CALL "MIN",P,Mn,J
2000 Mx=ABS(Mx) MAX ABS(Mn)
2030 VIEWPORT 15,65,25,65
2040 WINDOW 0,5,-Mx*5/4,Mx*5/4
2050 AXIS 1,Mx/4
2060 FOR K=1 TO 5
2062    MOVE K,0
2064    DRAW K,P(K)
2066 NEXT K
2070 HOME
2071 PRINT "JJ"
2072 PRINT " *** MEASUREMENT NUMBER *** : ";I;"/";M
2073 PRINT "JJJJJJJJJJJJJJJJJJJJJJJJJJ"
2075 PRINT "    COR =";Ww(I),"# OF SAMPLES=";N1;" TIMES ";Av
2077 RETURN
2080 REM
2085 REM
2086 REM
2087 REM
2090 REM
2100 REM *** TOTAL MEASUREMENT PLOT SUBR. ***
2102 PAGE
2110 CALL "MAX",Ww,Mx,J
```

```
2120 CALL "MIN",Ww,Mn,J
2122 Mm=ABS(Mx) MAX ABS(Mn)
2130 VIEWPORT 15,105,45,95
2134 IF Mn<=0 THEN 2140
2136 Mn=0
2140 WINDOW 0,M,Mn*5/4,Mx*5/4
2150 AXIS M,Mm/4
2160 FOR I=1 TO M
2170    MOVE I,0
2180    DRAW I,Ww(I)
2190 NEXT I
2200 REM
2350 HOME
2355 PRINT "                                    CROSSCORRELATION "
2380 INPUT G$
2390 PAGE
2400 RETURN
3000 REM *** FFT SUBROUTINE ***
3010 N2=1+M/2
3310 DELETE Mg,P
3320 DIM Mg(N2),P(N2)
3330 Mg=0
3340 P=0
3350 PRINT "JJJ";"NEED TO CHANGE THE TAPER FACTOR? (Y/RTN)"
3352 PRINT "J";" NO TAPERING     : (RTN)"
3353 PRINT " PREVIOUS VALUE : ";Tp
3354 INPUT G$
3360 IF G$<>"Y" THEN 3370
3362 PRINT "INPUT NEW VALUE"
3364 INPUT Tp
3366 GO TO 3380
3370 Tp=0
3380 Wf=Ww
3382 CALL "TAPER",Wf,Tp
3390 CALL "FFT",Wf
```

```
3400 CALL "POLAR",Wf,Mg,P,0
4000 REM *** WAVEFORM AND SPECTRUM PLOT SUBR. ***
4100 PAGE
4110 CALL "MAX",Ww,Mx,L
4120 CALL "MIN",Ww,Mn,L
4122 Mm=ABS(Mx) MAX ABS(Mn)
4130 Dw=Mx-Mn
4140 VIEWPORT 40,105,60,95
4142 Mz=Mn
4144 IF Mz<=0 THEN 4150
4146 Mz=0
4150 WINDOW 0,M,Mz,Mx
4160 AXIS M,Mm/10
4170 FOR I=1 TO M
4180    MOVE I,0
4182    DRAW I,Ww(I)
4184 NEXT I
4200 REM
4210 CALL "MAX",Mg,Ma,L
4230 VIEWPORT 40,105,15,50
4260 WINDOW 0,N2,0,Ma
4270 AXIS N2,Ma/10
4280 FOR I=1 TO N2
4282    MOVE I,0
4284    DRAW I,Mg(I)
4286 NEXT I
4290 REM
4292 REM
4294 REM
4600 REM *** LETTERING ***
4700 Tr=H
4710 Tr=INT(Tr*1000)/1000
4720 Tw=N*Tr
4730 Mx=INT(Mx*1000000)/1000000
4740 Mn=INT(Mn*1000000)/1000000
```

```
4750 Dw=INT(Dw*1000000)/1000000
4800 Fr=1/(H*M)*1000
4810 Fr=INT(Fr*1000)/1000
4812 N3=N2-1
4820 Fw=N3*Fr
4830 Ma=INT(Ma*1000)/1000
4940 REM
5000 HOME
5020 PRINT "NUMBER OF SAMPLE POINTS : ";N1;" TIMES ";Av
5030 PRINT "JJJ";"WAVEFORM"
5040 PRINT " MES : ";M;" PTS."
5042 PRINT " RES : ";Tr;" PS."
5050 PRINT " WIN : ";Tw;" PS."
5052 PRINT " MAX : ";Mx
5054 PRINT " MIN : ";Mn
5057 PRINT " DYN : ";Dw
5060 PRINT "JJJJJJJJJJ";"SPECTRUM"
5070 PRINT " MES : ";N2;" PTS."
5075 PRINT " RES : ";Fr;" GHZ"
5080 PRINT " WIN : ";Fw;" GHZ"
5090 PRINT " MAX : ";Ma
5100 PRINT " TAPER FCT. : ";Tp
5110 PRINT " (HANNING WINDOW)"
5200 INPUT G$
5210 PAGE
5510 RETURN
```

```
100 REM ***** PROGRAM FILE NO.2 *************************************
110 REM
120 REM
130 PAGE
140 PRINT "*** TIME DECONVOLUTION PROGRAM FOR NOISE SOURCE DATA ***"
150 PRINT "INSERT THE DATA TAPE IN THE TAPE DRIVE AND TYPE <RETURN>."
160 INPUT G$
170 PRINT "NOMINATOR DATA TAPE FILE NUMBER?"
180 INPUT Ta
190 FIND @33:Ta
200 READ @33:W$,D$,D,D,D,D,D,N1,X1,D,Tp,D
210 DELETE W0,W01,W02,Wt,Wt1,Wt2,Dm1,Dm2
220 DIM W0(N1),W01(N1),W02(N1),Wt(N1),Wt1(N1),Wt2(N1),Dm1(N1),Dm2(N1)
230 READ @33:W01,Wt1,Dm1,Dm2
240 REM
252 REM
254 REM
270 PRINT "DENOMINATOR DATA TAPE FILE NUMVER?"
280 INPUT Ta2
290 FIND @33:Ta2
300 READ @33:Nw$,D$,D,D,D,D,D,N2,X2,D,Tp,D
310 IF N1<>N2 THEN 320
312 IF X1<>X2 THEN 340
314 GO TO 360
320 PRINT "ERROR *** THE NUMBER OF THE SAMPLES IS NOT MATCHED!"
330 GO TO 730
340 PRINT "ERROR *** TIME RESOLUTION IS MISMATCHED!"
350 GO TO 730
360 READ @33:W02,Wt2,Dm1,Dm2
370 REM
380 REM
390 REM
400 REM *** START COMPUTATION ***
410 GOSUB 3000
```

```
420 REM
430 REM
440 REM
570 PAGE
580 PRINT "NEED SAVE DATA (Y/N)?"
590 INPUT G$
600 IF G$="N" THEN 700
610 PRINT "INSERT THE DATA TAPE IN THE TAPE DRIVE AND HIT <RETURN>."
620 INPUT G$
630 PRINT "TAPE FILE NUMBER?"
640 INPUT Ta
650 FIND @33:Ta
652 PRINT "TEST ID?"
654 INPUT W$
656 Av=1000
658 Tp=Sm
660 WRITE @33:W$,D$,D,D,D,D,D,N1,X1,D,Tp,Sm,W0,Wt,Dm1,Dm2
700 PRINT "NEED MORE TEST? (Y/N)"
710 INPUT G$
720 IF G$="Y" THEN 290
730 PRINT "BYE."
740 REM
750 REM
760 REM
770 REM
780 REM
800 END
3000 REM *** COMPUTE AND PLOT SUBR. ***
3100 PAGE
3200 REM *** PERFORM RIAD'S DECONVOLUTION
3300 N2=1+N1/2
3310 DELETE Mg,Mg1,Mg2,Mgt,P,P1,P2
3320 DIM Mg(N2),Mg1(N2),Mg2(N2),Mgt(N2),P(N2),P1(N2),P2(N2)
3330 CALL "POLAR",Wt1,Mg1,P1,0
3340 CALL "POLAR",Wt2,Mg2,P2,0
```

```
3350 PRINT " INPUT SMOOTH PARAMETER. (SM)=0)"
3360 INPUT Sm
3370 Mgt=Mg2↑2
3380 Sm1=Sm*SUM(Mgt)/N2
3390 Mgt=Mgt+Sm1
3400 REM
3410 Mg=Mg1*Mg2
3420 Mg=Mg/Mgt
3430 P=P1-P2
3440 REM
3450 REM
3460 REM
3470 REM *** GET RECTANGULAR VALUE.
3500 FOR I=1 TO N2-1
3510    J=2*I-1
3520    J2=2*I
3530    Wt(J)=Mg(I)*COS(P(I))
3540    Wt(J2)=Mg(I)*SIN(P(I))
3550 NEXT I
3560 Wt(1)=Mg(1)
3570 Wt(N1)=Mg(N2)
3580 REM
3590 REM *** GET IMPULSE RESPONSE.
3600 W0=Wt
3610 CALL "IFT",W0
3640 REM
3650 REM
3660 REM
3670 REM
3680 REM
3990 Rt=0
4000 REM *** PLOT THE GRAPHS ***
4002 PRINT "DO YOU NEED FULL SIZE PLOT?(RTN/N)"
4004 INPUT G$
4006 IF G$="N" THEN 4018
```

```
4000 Ti=1
4010 Ts=N1
4011 Tz=Ts
4012 Fs=N2
4014 GO TO 4100
4018 PRINT "HOW MANY TIME POINTS NEED TO SEE?"
4020 PRINT "START POINT?"
4030 INPUT Ti
4040 PRINT "SIZE?"
4050 INPUT Tz
4060 Ts=Ti+Tz-1
4070 PRINT "HOW MANY FREQUENCY POINTS NEED TO SEE? (SIZE)"
4080 INPUT Fs
4090 PAGE
4100 REM *** PLOT NOMINATOR SIGNAL ***
4102 PAGE
4110 CALL "MAX",W01,Mx,L
4120 CALL "MIN",W01,Mn,L
4122 Mm=ABS(Mx) MAX ABS(Mn)
4130 Dw1=Mx-Mn
4140 VIEWPORT 25,65,70,90
4170 WINDOW Ti,Ts,Mn,Mx
4180 AXIS Ts/4,Mm/4
4190 CALL "DISP",W01
4192 REM
4194 REM
4196 REM
4210 CALL "MAX",Mg1,Ma1,L
4230 VIEWPORT 70,110,70,90
4260 WINDOW 1,Fs,0,Ma1
4270 AXIS Fs/4,Ma1/4
4280 CALL "DISP",Mg1
4290 REM
4292 REM
4294 REM
```

```
4300 REM *** PLOT DENOMINATOR SIGNAL ***
4310 CALL "MAX",W02,Mx,L
4320 CALL "MIN",W02,Mn,L
4322 Mm=ABS(Mx) MAX ABS(Mn)
4330 Dw2=Mx-Mn
4340 VIEWPORT 25,65,48,68
4350 WINDOW Ti,Ts,Mn,Mx
4360 AXIS Ts/4,Mm/4
4370 CALL "DISP",W02
4380 REM
4390 REM
4392 REM
4400 CALL "MAX",Mg2,Ma2,L
4410 VIEWPORT 70,110,48,68
4420 WINDOW 1,Fs,0,Ma2
4430 AXIS Fs/4,Ma2/4
4440 CALL "DISP",Mg2
4450 REM
4460 REM
4470 REM
4500 REM *** PLOT THE TARGET RESPONSE ***
4510 CALL "MAX",W0,Mx,L
4520 CALL "MIN",W0,Mn,L
4530 Mm=ABS(Mx) MAX ABS(Mn)
4540 Dw=Mx-Mn
4550 VIEWPORT 25,65,26,46
4560 WINDOW Ti,Ts,Mn,Mx
4570 AXIS Ts/4,Mm/4
4580 CALL "DISP",W0
4582 REM
4584 REM
4590 REM
4600 CALL "MAX",Mg,Ma,L
4610 VIEWPORT 70,110,26,46
4620 WINDOW 1,Fs,0,Ma
```

```
4630 AXIS Fs/4,Ma/4
4640 CALL "DISP",Mg
4650 REM
4660 REM
4700 REM *** LETTERING ***
4702 Tr=X1
4710 Tr=INT(Tr*1000)/1000
4720 Tw=Tz*Tr
4730 Mx=INT(Mx*1000)/1000
4740 Mn=INT(Mn*1000)/1000
4750 Dw=INT(Dw*1000)/1000
4800 Fr=1/(X1*N1)*1000
4810 Fr=INT(Fr*1000)/1000
4820 Fw=(Fs-1)*Fr
4830 Ma=INT(Ma*1000)/1000
5000 HOME
5020 PRINT "NUMBER OF SAMPLE POINT : ";N1;"J"
5030 PRINT "                  WAVEFORM                        SPECTRUM "
5040 PRINT "JJ";" TEST WITH"
5050 PRINT "  TARGET";"JJJJJJ"
5060 PRINT "  TEST WITHOUT"
5070 PRINT "  TARGET";"JJJJJJ"
5080 PRINT "  TARGET"
5090 PRINT "  RESPONSE";"JJJJJ"
5100 PRINT "             SMP. : ";Tz;" PTS. "
5120 PRINT "             RES. : ";Tr;" PSEC."
5130 PRINT "             WIN. : ";Tw;" PSEC."
5140 PRINT "             MAX. : ";Mx
5150 PRINT "             MIN. : ";Mn
5160 PRINT "             DYN. : ";Dw
5200 HOME
5210 PRINT "JJJJJJJJJJJJJJJJJJJJJJJJJJJJ"
5220 PRINT "                              SMP. : ";Fs;" PTS."
5230 PRINT "                              RES. : ";Fr;" GHZ."
5240 PRINT "                              WIN. : ";Fw;" GHZ."
```

```
5250 PRINT "                                              MAX. : ";Ma
5270 PRINT "                                              SMOOTH FCT. : ";Sm
5272 PRINT "                                              ROTATE PTS. : ";Rt
5280 HOME
5300 INPUT G$
5310 PAGE
5400 PRINT " WANT TRY AGAIN WITH ANOTHER SMOOTH FACTOR? (RTN/N)"
5410 INPUT G$
5420 IF G$="N" THEN 5500
5430 PRINT " INPUT NEW SMOOTH FACTOR. "
5440 PRINT " PREVIOUS VALUE : ";Sm
5450 INPUT Sm
5460 GO TO 3370
5500 PRINT " NEED TO ROTATE TARGET IMPULSE RESPONSE?(RTN/N)"
5520 INPUT G$
5530 IF G$="N" THEN 6000
5540 Rp=Rt
5550 PRINT "HOW MUCH POINT NEED TO ROTATE RIGHT?"
5555 PRINT " PREVIOUS VALUE : ";Rt
5560 INPUT Rt
5570 Rp=Rt-Rp
5580 FOR I=1 TO N1
5590    J=I+Rp
5600    IF J<=N1 THEN 5620
5610    J=J-N1
5612    GO TO 5626
5620    IF J>0 THEN 5626
5622    J=J+N1
5626    Dm1(J)=W0(I)
5630 NEXT I
5640 Dm2=W0
5650 W0=Dm1
5660 GO TO 4100
6000 PAGE
6010 RETURN
```

```
100 REM ***** FILE NUMBER 3 *************************************
101 REM
102 REM
103 PAGE
105 PRINT "*** SINGLE CHANEL PULSE ANALYSIS PROGRAM ***";"JJJ"
120 PRINT "IS THIS THE INITIAL RUN (Y/N)?"
130 INPUT I$
140 IF I$<>"N" THEN 260
142 REM
144 REM
146 REM
150 PRINT "INSERT THE DATA TAPE IN THE TAPE DRIVE AND TYPE <RETURN>."
160 INPUT G$
170 PRINT "TAPE FILE NUMBER?"
180 INPUT Ta
190 FIND @33:Ta
200 READ @33:W$,N1,X,Av,Dc
210 DELETE W0,Wt
220 DIM W0(N1),Wt(N1)
230 READ @33:W0,Wt
240 GOSUB 3000
250 GO TO 600
252 REM
254 REM
256 REM
258 Dc=0
260 PRINT "TEST ID?"
270 INPUT W$
290 PRINT "NUMBER OF TIME POINTS? (CHOOSE ONE)"
300 PRINT " <1>:128  <2>:256  <3>:512  <4>:1024 "
310 INPUT R
320 N1=128*2↑(R-1)
330 PRINT "NUMBER OF AVERAGE? (1 - 999)"
340 INPUT Av
```

```
342 A1=INT(Av/100)
344 A2=INT((Av-A1*100)/10)
346 A3=Av-A1*100-A2*10
350 Tp=0
355 Dc=0
360 REM
370 REM
380 REM
400 PRINT "NEED TO MEASURE DC VALUE? (Y/RTN)"
405 PRINT "FOR THE BETTER SPECTRUM ANALYSIS "
410 INPUT G$
420 IF G$<>"Y" THEN 500
422 PAGE
430 PRINT "PREFORM DC BIAS MEASUREMENT. (RTN)"
432 INPUT G$
440 GOSUB 1000
450 Dc=SUM(W0)/N1
500 REM *** START TEST ***
501 PAGE
502 PRINT "PERFORM SIGNAL MEASUREMENT. (RTN)"
504 INPUT G$
510 GOSUB 1000
512 W0=W0-Dc
520 GOSUB 3000
530 REM
540 REM
550 REM
600 PRINT "NEED SAVE DATA? (Y/N)"
610 INPUT G$
620 IF G$<>"Y" THEN 700
630 PRINT "INSERT THE DATA TAPE IN THE TAPE DRIVE AND HIT <RETURN>."
640 INPUT G$
650 PRINT "TAPE FILE NUMBER?"
660 INPUT Ta
670 FIND @33:Ta
```

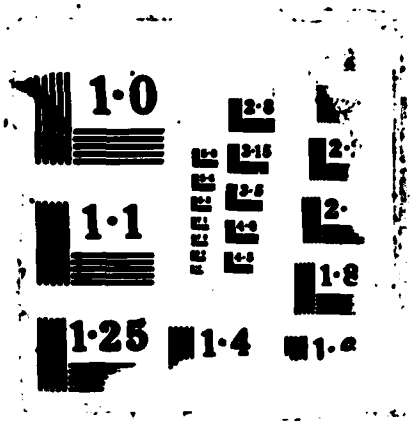
```
680 WRITE @33:W$,N1,X,Av,Dc,W0,Wt
700 PRINT "NEED MORE TEST? (Y/N)"
710 INPUT G$
720 IF G$="Y" THEN 290
730 PRINT "BYE."
740 REM
750 REM
760 REM
800 END
1000 REM *** MEASUREMENT SUBROUTINE ***
1010 PAGE
1020 PRINT "JJJJ"
1030 PRINT "      TYPE <RETURN> FOR THE MEASRTEMENT."
1040 INPUT G$
1100 GO TO R OF 1102,1110,1130,1150
1102 PRINT @10:"1 2 8 >P/W"
1104 GO TO 1200
1110 PRINT @10:"2 5 6 >P/W"
1120 GO TO 1200
1130 PRINT @10:"5 1 2 >P/W"
1140 GO TO 1200
1150 PRINT @10:"1 0 2 4 >P/W"
1160 REM
1170 REM
1180 REM
1200 DELETE W0,Wt
1210 DIM W0(N1),Wt(N1)
1300 ON SRQ THEN 1500
1302 PRINT @10:A1;A2;A3;" AVG"
1310 S=0
1320 PRINT @10:"AQR"
1330 IF S<>66 THEN 1330
1340 REM
1350 PRINT @10:"0 WFM SENDX"
1360 IF S<>210 THEN 1360
```

```
1370 INPUT @10:N1,Z1,X,Z2,Y
1380 INPUT @10:W0
1390 W0=W0*Y
1400 W0=W0+Z2
1500 POLL D,S;10
1510 RETURN
1520 RETURN
1530 REM
1540 REM
1550 REM
3000 REM *** COMPUTE AND PLOT SUBR. ***
3100 PAGE
3300 N2=1+N1/2
3310 DELETE Mg,P
3320 DIM Mg(N2),P(N2)
3330 Mg=0
3340 P=0
3356 Wt=W0
3362 CALL "FFT",Wt
3370 CALL "POLAR",Wt,Mg,P,0
3380 REM
3390 REM
3400 REM
4000 REM *** PLOT THE GRAPHS ***
4002 PRINT "DO YOU NEED FULL SIZE PLOT?(RTN/N)"
4004 INPUT G$
4006 IF G$="N" THEN 4018
4008 Ti=1
4010 Ts=N1
4012 Tz=Ts
4014 Fs=N2
4016 GO TO 4100
4018 PRINT "HOW MANY TIME POINTS NEED TO SEE?"
4020 PRINT "START POINT?"
4030 INPUT Ti
```

```
4040 PRINT "SIZE?"
4050 INPUT Tz
4060 Ts=Ti+Tz-1
4070 PRINT "HOW MANY FREQUENCY POINTS NEED TO SEE?"
4080 INPUT Fs
4090 PAGE
4100 REM *** WAVEFORM PLOT ***
4102 PAGE
4110 CALL "MAX",W0,Mx,L
4120 CALL "MIN",W0,Mn,L
4122 Mxx=ABS(Mx) MAX ABS(Mn)
4130 Dw=Mx-Mn
4140 VIEWPORT [illegible]0,105,60,95
4170 WINDOW Ti,Ts,Mn,Mx
4180 AXIS Tz/8,Mxx/5
4190 CALL "DISP",W0
4192 REM
4194 REM
4196 REM
4200 REM *** SPECTRUM PLOT ***
4210 CALL "MAX",Mg,Ma,L
4230 VIEWPORT 40,105,15,50
4260 WINDOW 1,Fs,0,Ma
4270 AXIS Fs/8,Ma/10
4280 CALL "DISP",Mg
4290 REM
4292 REM
4294 REM
4600 REM *** LETTERING ***
4700 Tr=X*10↑12
4710 Tr=INT(Tr*1000)/1000
4720 Tw=N1*Tr
4730 Mx=INT(Mx*1000)/1000
4740 Mn=INT(Mn*1000)/1000
4750 Dw=INT(Dw*1000)/1000
```

AD-A195 086 SCATTERIN IMPULSE RESPONSE SYNTHESIS USING RANDOM 2/2
NOISE ILLUMINATION: INITIAL CONCEPT EVALUATION(U) NAVAL
POSTGRADUATE SCHOOL MONTEREY CA D I LEE MAR 88

UNCLASSIFIED F/G 17/9 NL


1·0
1·1
1·25
1·4
1·8

```
4760 Dc=INT(Dc*1000)/1000
4800 Fr=1/(X*N1)*10↑-9
4810 Fr=INT(Fr*1000)/1000
4820 Fw=N2*Fr
4830 Ma=INT(Ma*1000)/1000
4840 REM
5000 HOME
5020 PRINT "NUMBER OF SAMPLE POINT : ";N1
5030 PRINT "JJJ";"WAVEFORM"
5040 PRINT " SMP : ";N1;" PTS."
5045 PRINT " RES : ";Tr;" PS. "
5050 PRINT " WIN : ";Tw;" PS. "
5052 PRINT " MAX : ";Mx;" VLT"
5054 PRINT " MIN : ";Mn;" VLT";"      ";Ti;
5055 PRINT "                              ";Ts
5056 PRINT " DYN : ";Dw;" VLT"
5058 PRINT " BIAS: ";Dc;" VLT"
5059 PRINT " AVG : ";Av;" TIMES"
5060 PRINT "JJJJJJJ";"SPECTRUM"
5070 PRINT " SMP : ";N2;" PTS."
5075 PRINT " RES : ";Fr;" GHZ"
5080 PRINT " WIN : ";Fw;" GHZ"
5090 PRINT " MAX : ";Ma;" VLT"
5120 PRINT "JJJ";"
5130 PRINT "    ";Fs
5200 INPUT G$
5210 PAGE
5400 PRINT "WANT PLOT AGAIN WITH DIFFERENT WINDOW? (RTN/N)"
5410 INPUT G$
5420 IF G$="N" THEN 5500
5430 GO TO 4018
5470 REM
5500 PAGE
5510 RETURN
```

```
100 REM *** FILE NO. 4 **********************************************
110 REM
142 REM
144 REM
146 PAGE
148 PRINT "*** TIME DECONVOLUTION FOR PULSE MEASUREMENT ***";"JJJ"
150 PRINT "INSERT THE DATA TAPE IN THE TAPE DRIVE AND TYPE <RETURN>."
160 INPUT G$
170 PRINT "NOMINATOR DATA TAPE FILE NUMBER?"
180 INPUT Ta
190 FIND @33:Ta
200 READ @33:W$,N1,X1,Av,Dc
210 DELETE W0,W01,W02,Wt,Wt1,Wt2
220 DIM W0(N1),W01(N1),W02(N1),Wt(N1),Wt1(N1),Wt2(N1)
230 READ @33:W01,Wt1
240 REM
252 REM
254 REM
270 PRINT "DENOMINATOR DATA TAPE FILE NUMUER?"
280 INPUT Ta2
290 FIND @33:Ta2
300 READ @33:Ww$,N2,X2,Av,Dm
310 IF N1<>N2 THEN 320
312 IF X1<>X2 THEN 340
314 GO TO 360
320 PRINT "ERROR *** THE NUMBER OF THE SAMPLES IS NOT MATCHED!"
330 GO TO 730
340 PRINT "ERROR *** TIME RESOLUTION IS MISMATCHED!"
350 GO TO 730
360 READ @33:W02,Wt2
370 REM
380 REM
390 REM
400 REM *** START COMPUTATION ***
```

```
410 GOSUB 3000
420 REM
430 REM
440 REM
570 PAGE
580 PRINT "NEED SAVE DATA (Y/N)?"
590 INPUT G$
600 IF G$="N" THEN 700
610 PRINT "INSERT THE DATA TAPE IN THE TAPE DRIVE AND HIT <RETURN>."
620 INPUT G$
630 PRINT "TAPE FILE NUMBER?"
640 INPUT Ta
650 FIND @33:Ta
652 PRINT "TEST ID?"
654 INPUT W$
656 Av=1000
658 Tp=Sm
660 WRITE @33:W$,N1,X1,Av,Dc,W0,Wt
700 PRINT "NEED MORE TEST? (Y/N)"
710 INPUT G$
720 IF G$="Y" THEN 290
730 PRINT "BYE."
740 REM
750 REM
760 REM
770 REM
780 REM
800 END
3000 REM *** COMPUTE AND PLOT SUBR. ***
3100 PAGE
3200 REM *** PERFORM RIAD'S DECONVOLUTION
3300 N2=1+N1/2
3310 DELETE Mg,Mg1,Mg2,Mgt,P,P1,P2
3320 DIM Mg(N2),Mg1(N2),Mg2(N2),Mgt(N2),P(N2),P1(N2),P2(N2)
3330 CALL "POLAR",Wt1,Mg1,P1,0
```

```
3340 CALL "POLAR",Wt2,Mg2,P2,0
3350 PRINT " INPUT SMOOTH PARAMETER."
3360 INPUT Sm
3370 Mgt=Mg2↑2
3380 Sm1=Sm*SUM(Mgt)/N2
3390 Mgt=Mgt+Sm1
3400 REM
3410 Mg=Mg1*Mg2
3420 Mg=Mg/Mgt
3430 P=P1-P2
3440 REM
3450 REM
3460 REM
3470 REM *** GET RECTANGULAR VALUE.
3500 FOR I=1 TO N2-1
3510    J=2*I-1
3520    J2=2*I
3530    Wt(J)=Mg(I)*COS(P(I))
3540    Wt(J2)=Mg(I)*SIN(P(I))
3550 NEXT I
3560 Wt(1)=Mg(1)
3570 Wt(N1)=Mg(N2)
3580 REM
3590 REM *** GET IMPULSE RESPONSE.
3600 W0=Wt
3610 CALL "IFT",W0
3640 REM
3650 REM
3660 REM
3670 REM
3680 REM
4000 REM *** PLOT THE GRAPHS ***
4002 PRINT "DO YOU NEED FULL SIZE PLOT?(RTN/N)"
4004 INPUT G$
4006 IF G$="N" THEN 4018
```

```
4008 Ti=1
4010 Ts=N1
4011 Tz=Ts
4012 Fs=N2
4014 GO TO 4100
4018 PRINT "HOW MANY TIME POINTS NEED TO SEE?"
4020 PRINT "START POINT?"
4030 INPUT Ti
4040 PRINT "SIZE?"
4050 INPUT Tz
4060 Ts=Ti+Tz-1
4070 PRINT "HOW MANY FREQUENCY POINTS NEED TO SEE? (SIZE)"
4080 INPUT Fs
4090 PAGE
4100 REM *** PLOT NOMINATOR SIGNAL ***
4102 PAGE
4110 CALL "MAX",W01,Mx,L
4120 CALL "MIN",W01,Mn,L
4122 Mm=ABS(Mx) MAX ABS(Mn)
4130 Dw1=Mx-Mn
4140 VIEWPORT 25,65,70,90
4170 WINDOW Ti,Ts,Mn,Mx
4180 AXIS Ts/4,Mm/4
4190 CALL "DISP",W01
4192 REM
4194 REM
4196 REM
4210 CALL "MAX",Mg1,Ma1,L
4230 VIEWPORT 70,110,70,90
4260 WINDOW 1,Fs,0,Ma1
4270 AXIS Fs/4,Ma1/4
4280 CALL "DISP",Mg1
4290 REM
4292 REM
4294 REM
```

```
4300 REM *** PLOT DENOMINATOR SIGNAL ***
4310 CALL "MAX",W02,Mx,L
4320 CALL "MIN",W02,Mn,L
4322 Ma=ABS(Mx) MAX ABS(Mn)
4330 Dw2=Mx-Mn
4340 VIEWPORT 25,65,48,68
4350 WINDOW Ti,Ts,Mn,Mx
4360 AXIS Ts/4,Ma/4
4370 CALL "DISP",W02
4380 REM
4390 REM
4392 REM
4400 CALL "MAX",Mg2,Ma2,L
4410 VIEWPORT 70,110,48,68
4420 WINDOW 1,Fs,0,Ma2
4430 AXIS Fs/4,Ma2/4
4440 CALL "DISP",Mg2
4450 REM
4460 REM
4470 REM
4500 REM *** PLOT THE TARGET RESPONSE ***
4510 CALL "MAX",W0,Mx,L
4520 CALL "MIN",W0,Mn,L
4530 Ma=ABS(Mx) MAX ABS(Mn)
4540 Dw=Mx-Mn
4550 VIEWPORT 25,65,26,46
4560 WINDOW Ti,Ts,Mn,Mx
4570 AXIS Ts/4,Ma/4
4580 CALL "DISP",W0
4582 REM
4584 REM
4590 REM
4600 CALL "MAX",Mg,Ma,L
4610 VIEWPORT 70,110,26,46
4620 WINDOW 1,Fs,0,Ma
```

```
4630 AXIS Fs/4,Ma/4
4640 CALL "DISP",Mg
4650 REM
4660 REM
4700 REM *** LETTERING ***
4702 Tr=X1*10↑12
4710 Tr=INT(Tr*1000)/1000
4720 Tw=Tz*Tr
4730 Mx=INT(Mx*1000)/1000
4740 Mn=INT(Mn*1000)/1000
4750 Dw=INT(Dw*1000)/1000
4800 Fr=1/(X1*N1)*10↑-9
4810 Fr=INT(Fr*1000)/1000
4820 Fw=Fs*Fr
4830 Ma=INT(Ma*1000)/1000
5000 HOME
5020 PRINT "NUMBER OF SAMPLE POINT : ";N1;"J"
5030 PRINT "                    WAVEFORM                    SPECTRUM "
5040 PRINT "JJ";" TEST WITH"
5050 PRINT " TARGET";"JJJJJJ"
5060 PRINT " TEST WITHOUT"
5070 PRINT " TARGET";"JJJJJJ"
5080 PRINT " TARGET"
5090 PRINT " RESPONSE";"JJJJJ"
5100 PRINT "               SMP. : ";Tz;" PTS. "
5120 PRINT "               RES. : ";Tr;" PSEC."
5130 PRINT "               WIN. : ";Tw;" PSEC."
5140 PRINT "               MAX. : ";Mx;" ULT."
5150 PRINT "               MIN. : ";Mn;" ULT."
5160 PRINT "               DYN. : ";Dw;" ULT."
5200 HOME
5210 PRINT "JJJJJJJJJJJJJJJJJJJJJJJJJJJJ"
5220 PRINT "                                        SMP. : ";Fs;" PTS."
5230 PRINT "                                        RES. : ";Fr;" GHZ."
5240 PRINT "                                        WIN. : ";Fw;" GHZ."
```

```
5250 PRINT "                                                    MAX. : ";Ma;" VLT.J"
5270 PRINT "                                                    SMOOTH FCT. : ";Sm
5280 HOME
5300 INPUT G$
5310 PAGE
5400 PRINT " WANT TRY AGAIN WITH ANOTHER SMOOTH FACTOR? (RTN/N)"
5410 INPUT G$
5420 IF G$="N" THEN 5500
5430 PRINT " INPUT NEW SMOOTH FACTOR. "
5440 PRINT " PREVIOUS VALUE : ";Sm
5450 INPUT Sm
5460 GO TO 3370
5470 REM
5500 PAGE
5510 RETURN
```

```
100 REM ***** PROGRAM FILE NO.10 ****************************************
105 REM ***** NOISE SOURCE CROSSCORRELATION MEASUREMENT PROGRAM USING
106 REM ***** INNER PRODUCT METHOD (METHOD NO.2)
107 REM ***** DPO VERTICAL MODE : ALT
108 REM
109 REM
110 PAGE
115 PRINT "NOISE SOURCE CROSSCORRELATION MEASUREMENT PROGRAM"
116 PRINT "USING METHOD NO. 2"
120 PRINT "JJ"
130 PRINT "IS THIS THE INITIAL RUN? (Y/N)"
140 INPUT Y$
150 IF Y$="N" THEN 430
170 REM
180 REM
190 REM
200 REM
205 Cr=0
210 PRINT "TEST (WAVEFORM) ID?"
220 INPUT W$
270 PRINT "TAPE FILE NUMBER?"
280 INPUT Ta
290 PRINT "NUMBER OF MEASUREMENT? ( POWER OF 2 ===) 16, 32, 64, 128 ) "
292 INPUT M
300 PRINT "NUMBER OF TIME POINTS? (CHOOSE ONE)"
302 PRINT "  (1):256   (2):512   (3):1024 "
304 INPUT R
310 PRINT "NUMBER OF SAMPLE SETS?"
315 INPUT Av
340 PRINT "HOR. SCALE (TIME) IN PICOSEC.?"
350 INPUT H
360 PRINT "VER. SCALE (VOLTAGE) IN MILLIVOLT?"
362 INPUT V
370 REM
```

```
374 Tp=0
380 M1=0
382 IF Cr=2 THEN 390
384 DELETE Ww,Wf,Ur0,Ur1
386 DIM Ww(M),Wf(M),Ur0(M),Ur1(M)
390 GO TO 530
400 REM
410 REM
420 REM
430 PRINT "INSERT THE DATA TAPE IN THE TAPE DRIVE AND TYPE <GO>."
440 INPUT G$
450 PRINT "TAPE FILE NUMBER?"
460 INPUT Talis
470 FIND @33:Ta
480 READ @33:N$,D$,Ta,D,R,Av,M,N,H,V,Tp,D
485 DELETE Ww,Wf,Ur0,Ur1
486 DIM Ww(M),Wf(M),Ur0(M),Ur1(M)
487 READ @33:Ww,Wf,Ur0,Ur1
490 REM
500 REM
510 REM
520 REM
525 REM
530 N1=128*2^R
535 Nt=N1*Av
540 GOSUB 1430
550 PRINT "DO YOU NEED ANY CORRECTION? "
552 PRINT " <1>:YES     <2>:YES, EXCEPT THE DATA MEASURED"
554 PRINT " <3>:NO      <4>:NO, WANT SIGNAL ANALYSIS"
560 INPUT Cr
570 GO TO Cr OF 210,210,580,1150
580 PRINT "WELL, NOW THE ITIALIZATION IS DONE."
590 PRINT "TYPE <GO> FOR THE NEXT STEP. (MEASUREMENT)"
600 INPUT G$
610 PRINT "GGGGGGGGGGGG"
```

```
620 REM
630 REM
640 REM
650 REM
670 PAGE
680 PRINT "PERFORMING THE MEASUREMENT"
690 PRINT "IS THIS A REPETATIVE MEASUREMENT? (Y/N)"
700 INPUT Rm$
710 IF Rm$="N" THEN 840
715 PRINT "INITIAL MEASUREMENT NUMBER?"
717 INPUT M1
720 FOR I=M1 TO M
725    M1=I
730    GOSUB 1620
735    GOSUB 1900
737    PAGE
740    PRINT "WANT THE NEXT MEASUREMENT?"
750    PRINT " <RETURN>:NEXT   <N>:NO"
755    INPUT G$
760    IF G$="N" THEN 770
765    GO TO 800
770    PRINT "TRY AGAIN, OR QUIT? (A/Q)"
775    INPUT G$
780    IF G$="A" THEN 790
785    GO TO 805
790    I=I-1
800 NEXT I
801 REM
802 REM
803 REM
805 PRINT "NEED THE NONREPETATIVE MEASUREMENT? (Y/N)"
807 INPUT Nm$
808 IF Nm$="N" THEN 940
810 REM
820 REM
```

```
830 REM
840 REM *** NON REPETATIVE MEASUREMENT ***
850 REM
870 GOSUB 1430
880 PRINT "MEASUREMENT NUMBER?"
890 INPUT M1
900 GOSUB 1620
905 GOSUB 1900
907 PAGE
910 PRINT "NEED ANOTHER MEASUREMENT? (Y/N)"
920 INPUT Ma$
930 IF Ma$="Y" THEN 840
935 PRINT "GGGGGGGGGGGGGG"
940 PRINT "NOW, YOU ARE OUT OF MEASUREMENT STEP."
950 PRINT "TYPE <GO> FOR THE NEXT STEP. (PLOT AND SAVE)"
960 INPUT G$
1000 REM
1110 REM
1120 REM
1130 REM
1140 REM
1150 GOSUB 2100
1151 PRINT "                    FREQUENCY CHARACTERISTIC COMPUTATION "
1152 GOSUB 3000
1160 PRINT "DO YOU WANT SAVE? (Y/N)"
1170 INPUT Ss$
1180 IF Ss$="N" THEN 1280
1190 PRINT "INSERT THE DATA TAPE IN THE TAPE DRIVE AND TYPE <GO>."
1200 INPUT G$
1204 PRINT "TAPE FILE NUMBER?"
1206 INPUT Ta
1210 FIND @33:Ta
1212 D$="DUMMY"
1214 D=0
1220 WRITE @33:W$,D$,Ta,D,R,Av,M,M,H,V,Tp,D,Ww,Wf,Vr0,Vr1
```

```
1230 REM
1240 REM
1250 REM
1260 REM
1280 PRINT "NOW, YOU ARE READY TO QUIT THE TEST"
1290 PRINT "DO YOU WANT TO TEST AGAIN? (Y/N)"
1300 INPUT Tt$
1310 IF Tt$="Y" THEN 520
1320 PRINT "THANK YOU FOR USING THIS PROGRAM."
1325 PRINT "PLEASE MAKE ANOTHER MEASUREMENT SOON."
1330 REM
1340 REM
1350 REM
1360 REM
1370 REM
1380 END
1390 REM***************************************
1400 REM
1410 REM
1420 REM
1430 REM *** CURRENT STATUS DISPLAY SUBR. ***
1440 PAGE
1445 PRINT "    *** CURRENT TEST STATUS ***"
1450 PRINT "JJ";
1460 PRINT "    TEST ( WAVE FORM ) ID    : ",W$
1490 PRINT "    TAPE FILE NUMBER         : ",Ta
1500 PRINT "J"
1510 PRINT "    NUMBER OF MEASUREMENT    : ",M
1515 PRINT "    NUMBER OF SAMPLE POINT   : ",N1;" TIMES ";Av
1520 PRINT "J"
1530 PRINT "    HOR. SCALE IN PICO SEC. : ",H
1540 PRINT "    VER. SCALE IN MILI VOLT : ",V
1550 PRINT "JJ"
1560 RETURN
1570 REM
```

```
1580 REM
1590 REM
1600 REM
1610 REM
1620 REM *** SCATTERING MEASUREMENT SUBROUTINE ***
1630 PAGE
1640 PRINT "JJ"
1650 PRINT " *** MEASUREMENT NUMBER *** : ";M;"/";M1
1660 PRINT "JJ"
1670 PRINT "CHANGE THE DELAY KNOB TO THE CURRENT STEP."
1680 PRINT "AND TYPE <GO> FOR THE MEASUREMENT."
1683 INPUT G$
1685 GO TO R OF 1688,1690,1692
1688 PRINT @10:"2 5 6 >P/W"
1689 GO TO 1700
1690 PRINT @10:"5 1 2 >P/W"
1691 GO TO 1700
1692 PRINT @10:"1 0 2 4 >P/W"
1693 REM
1694 REM
1695 REM
1700 DELETE W0,W1,Wr
1701 DIM W0(N1),W1(N1),Wr(N1)
1702 Men0=0
1704 Men1=0
1706 Vr0(M1)=0
1708 Vr1(M1)=0
1710 Wu(M1)=0
1712 FOR J=1 TO Av
1714    ON SRQ THEN 1820
1716    S=0
1718    PRINT @10:"AQR"
1720    IF S<>66 THEN 1720
1725    REM
1730    PRINT @10:"0 WFM SENDX"
```

```
1740    IF S<>210 THEN 1740
1750    INPUT @10:N1,Z1,X,Z2,Y
1760    INPUT @10:W0
1762    W0=W0*Y
1764    W0=W0+Z2
1776    REM
1780    PRINT @10:"1 WFM SENDX"
1790    IF S<>210 THEN 1790
1800    INPUT @10:N1,Z3,X1,Z4,Y1
1812    INPUT @10:W1
1814    W1=W1*Y1
1816    W1=W1+Z4
1818    GO TO 1830
1820    POLL D,S;10
1822    RETURN
1824    REM
1826    REM
1828    REM
1830    Men0=Men0+SUM(W0)/Nt
1832    Men1=Men1+SUM(W1)/Nt
1840    Wr=W0*W0
1842    Vr0(M1)=Vr0(M1)+SUM(Wr)/Nt
1844    Wr=W1*W1
1846    Vr1(M1)=Vr1(M1)+SUM(Wr)/Nt
1850    Wr=W0*W1
1852    Ww(M1)=Ww(M1)+SUM(Wr)/Nt
1860 NEXT J
1862 REM
1864 REM
1866 REM
1874 Vr0(M1)=Vr0(M1)-Men0*Men0
1876 Vr1(M1)=Vr1(M1)-Men1*Men1
1878 Ww(M1)=Ww(M1)-Men0*Men1
1879 Ww(M1)=Ww(M1)/SQR(Vr0(M1)*Vr1(M1))
1880 RETURN
```

```
1891 REM
1892 REM
1893 REM
1894 REM
1895 REM
1900 REM *** CURRENT MEASUREMENT PLOT SUBR. ***
1905 DELETE P
1910 DIM P(5)
1915 P=0
1920 GO TO M1 OF 1970,1960,1950,1940,1930
1930 P(1)=Ww(M1-4)
1940 P(2)=Ww(M1-3)
1950 P(3)=Ww(M1-2)
1960 P(4)=Ww(M1-1)
1970 P(5)=Ww(M1)
1980 CALL "MAX",P,Mx,J
1990 CALL "MIN",P,Mn,J
2000 Mx=ABS(Mx) MAX ABS(Mn)
2030 VIEWPORT 15,65,25,65
2040 WINDOW 0,5,-Mx*5/4,Mx*5/4
2050 AXIS 1,Mx/4
2060 FOR K=1 TO 5
2062    MOVE K,0
2064    DRAW K,P(K)
2066 NEXT K
2070 REM
2071 HOME
2072 PRINT "JJJJJJJJJJJJJJJJJJJJJJJJJJJJJ"
2073 PRINT "    VAR0=";Vr0(M1),"MEAN0=";Men0
2074 PRINT "    VAR1=";Vr1(M1),"MEAN1=";Men1
2075 PRINT "    COR =";Ww(M1),"# OF SAMPLES=";M1;" TIMES ";Av
2076 INPUT G$
2077 RETURN
2080 REM
2085 REM
```

```
2086 REM
2087 REM
2090 REM
2100 REM *** TOTAL MEASUREMENT PLOT SUBR. ***
2102 PAGE
2110 CALL "MAX",Ww,Mx,J
2120 CALL "MIN",Ww,Mn,J
2122 Mm=ABS(Mx) MAX ABS(Mn)
2130 VIEWPORT 15,105,45,95
2134 IF Mn<=0 THEN 2140
2136 Mn=0
2140 WINDOW 0,M,Mn*5/4,Mx*5/4
2150 AXIS M,Mm/4
2160 FOR I=1 TO M
2170    MOVE I,0
2180    DRAW I,Ww(I)
2190 NEXT I
2200 REM
2210 CALL "MAX",Vr0,Mx,J
2220 VIEWPORT 15,55,5,30
2230 WINDOW 0,M,0,Mx*5/4
2240 AXIS M/4,Mx/4
2250 CALL "DISP",Vr0
2290 REM
2300 CALL "MAX",Vr1,Mx,J
2310 VIEWPORT 65,105,5,30
2320 WINDOW 0,M,0,Mx*5/4
2330 AXIS M/4,Mx/4
2340 CALL "DISP",Vr1
2350 HOME
2355 PRINT "                   CORRELATION --- IMPULSE RESPONSE "
2360 PRINT "JJJJJJJJJJJJJJJJJJJJJJJ"
2370 PRINT "                CHANEL 0 VAR.                 CHANEL 1 VAR."
2380 INPUT G$
2390 PAGE
```

```
2400 RETURN
3000 REM *** FFT SUBROUTINE ***
3010 N2=1+M/2
3310 DELETE Mg,P
3320 DIM Mg(N2),P(N2)
3330 Mg=0
3340 P=0
3350 PRINT "JJJ";"NEED TO CHANGE THE TAPER FACTOR? (Y/RTN)"
3352 PRINT "J";" NO TAPERING     : <RTN>"
3353 PRINT " PREVIOUS VALUE : ";Tp
3354 INPUT G$
3360 IF G$<>"Y" THEN 3370
3362 PRINT "INPUT NEW VALUE"
3364 INPUT Tp
3366 GO TO 3380
3370 Tp=0
3380 Wf=Ww
3382 CALL "TAPER",Wf,Tp
3390 CALL "FFT",Wf
3400 CALL "POLAR",Wf,Mg,P,0
4000 REM *** WAVEFORM AND SPECTRUM PLOT SUBR. ***
4100 PAGE
4110 CALL "MAX",Ww,Mx,L
4120 CALL "MIN",Ww,Mn,L
4122 Mm=ABS(Mx) MAX ABS(Mn)
4130 Dw=Mx-Mn
4140 VIEWPORT 40,105,60,95
4142 Mz=Mn
4144 IF Mz<=0 THEN 4150
4146 Mz=0
4150 WINDOW 0,M,Mz,Mx
4160 AXIS M,Mm/10
4170 FOR I=1 TO M
4180    MOVE I,0
4182    DRAW I,Ww(I)
```

```
4184 NEXT I
4200 REM
4210 CALL "MAX",Mg,Ma,L
4230 VIEWPORT 40,105,15,50
4260 WINDOW 0,N2,0,Ma
4270 AXIS N2,Ma/10
4280 FOR I=1 TO N2
4282    MOVE I,0
4284    DRAW I,Mg(I)
4286 NEXT I
4290 REM
4292 REM
4294 REM
4600 REM *** LETTERING ***
4700 Tr=H
4710 Tr=INT(Tr*1000)/1000
4720 Tw=N*Tr
4730 Mx=INT(Mx*1000)/1000
4740 Mn=INT(Mn*1000)/1000
4750 Dw=INT(Dw*1000)/1000
4800 Fr=1/(H*M)*1000
4810 Fr=INT(Fr*1000)/1000
4812 N3=N2-1
4820 Fw=N3*Fr
4930 Ma=INT(Ma*1000)/1000
4840 REM
5000 HOME
5020 PRINT "NUMBER OF SAMPLE POINTS : ";N1;" TIMES ";Av
5030 PRINT "JJJ";"WAVEFORM"
5040 PRINT " MES : ";M;" PTS."
5042 PRINT " RES : ";Tr;" PS."
5050 PRINT " WIN : ";Tw;" PS."
5052 PRINT " MAX : ";Mx
5054 PRINT " MIN : ";Mn
5057 PRINT " DYN : ";Dw
```

```
5060 PRINT "JJJJJJJJJJ";"SPECTRUM"
5070 PRINT " MES : ";N3;" PTS."
5075 PRINT " RES : ";Fr;" GHZ"
5080 PRINT " WIN : ";Fw;" GHZ"
5090 PRINT " MAX : ";Ma
5100 PRINT " TAPER FCT. : ";Tp
5110 PRINT " (HANNING WINDOW)"
5200 INPUT G$
5210 PAGE
5510 RETURN
```

LIST OF REFERENCES

1. M.A. Morgan, *Time-Domain Scattering Measurements*, IEEE Antennas and Propagation Newsletter, Aug. 1984.

2. M.A. Morgan and B.W. McDaniel, *Transient Electromagnetic Scattering: Data Acquisition and Signal Processing*, IEEE Transactions on Instrumentation and Measurement, To be Published (Jun. 1988).

3. G.R. Cooper and C.D. McGillem, *Probabilistic Methods of Signal and System Analysis*, Holt, Rinehart and Winston, p. 300, 1971.

4. J.D. Lorenzo, *A Range for Measuring the Impulse Response of Scattering Objects*, 1967 NEREM (North East Electronics Research and Engineering Meeting) Rec., Vol. 9, pp. 80-81, Nov. 1967.

5. C.W. Hammond, *The Development of a Bistatic Electromagnetic Scattering Laboratory*, Masters Thesis, Naval Postgraduate School, Monterey, California, Dec. 1980.

6. L.A. Sorrentino, *Time Domain Radar Laboratory Operating System Development and Transient EM Analysis*, Masters Thesis, Naval Postgraduate School, Monterey, California, Sep. 1981.

7. M.L. Van Blaricum and R. Mittra, *A Technique for Extracting the Poles and Residues of a System Directly from Its Transient Response*, IEEE Transactions on Antennas and Propagation-23, pp. 777-781, Nov. 1976.

8. M.A. Mariategui, *Development, Calibration and Evaluation of a Free-Field Scattering Range*, Masters Thesis, Naval Postgraduate School, Monterey, California, Dec. 1983.

9. B.W. McDaniel, *Calibration and Evaluation of a Free-field Scattering Range Using Wideband Pulse Amplification*, Masters Thesis, Naval Postgraduate School, Monterey, California, Dec. 1983.

10. S.M. Riad, *Impulse Response Evaluation Using Frequency Domain Optimal Compensation Deconvolution*, 23rd Midwest Symposium on Circuits and Systems, University of Toledo, pp. 521-5, Aug. 1980.

11. Simon Haykin, *Communication Systems*, 2nd Edition, New York: Wiley, p. 59, 1983.

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